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ELEMENTARY LESSONS

IN THE

PRINCIPLES OF AGRICULTURE.

SPECIALLY ADAPTED TO THE REQUIREMENTS
OF THE NEW CODE OF 1882.

BY

W.m JEROME HARRISON, F.G.S,
Science Lecturer for the Birmingham School Board.

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PRINCIPLES OF AGRICULTURE.

I.—PLANT-FOOD IN THE SEED.

1. Plants require Food—2. Nature of Food in general—3. Food in the Seed—4. An Egg and a Seed.

1. Plants require Food.—Every one knows that animals require food, for we see that they soon languish and die if they cannot obtain a sufficient supply of it. Plants require food just as much as animals; and, like animals, they starve and perish if they cannot get a proper amount of the right kind of food. But it is not so easy to see plants take their food as it is to watch animals eating; and if we want to find out what *plant-food* is, we shall have to look very carefully. Perhaps we shall even require to ask the plants some questions—that is, try some experiments—in order to find out what kind of food they prefer, and how they take it in.

2. Nature of "Food" in general.—Of the three kingdoms of Nature—the animal, the vegetable, and the mineral—only the two former can be said to require food, or to eat. A mineral, or a stone, will be none the worse if it be not supplied with food of any kind; but if a plant or an animal is to grow, or even to continue to live, it must be supplied with food. Animals, however, require a different kind of food from that needed by plants. The food of an animal may consist of the flesh of other animals, or of the matter of plants. If we supply an animal with *mineral* matter only, we shall find that it cannot use this as food: animals cannot feed entirely upon such substances as water, earth, and air.

But the members of the vegetable kingdom—plants—can feed on mineral matter. In the first volume of this book we have seen how the portion of the soil which dissolves in water, or in water containing a little of certain weak acids, is used by plants as food. Entering by the root, this soluble or active part of the soil acts as food to the plant, sustaining and nourishing it, building up its cells and tissues, and helping to form the root, stem, branches, leaves, flowers, and fruit. It is true that there is one division of plants—the funguses, or mushrooms—which cannot live on mineral food, but which prefer decaying animal or vegetable matter; but these form an exception. We see, then, that there is a marked difference between the food of animals and the food of plants. The food of animals is chiefly organic matter, but the food of plants is chiefly inorganic (or mineral) matter.

3. Food in the Seed.—All seeds contain within themselves a small supply of food, which is sufficient for the young plant until it has put forth its root and one or two of its leaves; after which it has to seek food for itself. If we put a few broad beans to soak for a night in warm water, we shall be able easily to open the beans in the morning, and to notice the parts of which they are composed. If we look very carefully, we may see two tiny whitish projecting points lying between the two thick fleshy halves of the seed. One of the little projections is the young stem, and the other is the young root; the two thick halves of the seed are really the first pair of leaves, and they are called the *seed-leaves*. These leaves are so thick and fleshy because they contain a store of food for the young plant. If we keep the beans moist by wrapping them up in a piece of damp flannel, on which a little water is poured from time to time to keep up the supply of moisture, and if we also keep them in a warm place, as on the kitchen mantelpiece, we shall be able to watch the growth of the stem and root, while at the same time the seed-leaves shrink up and wither away. A supply of water is needful, because everything that a plant uses as food must be dissolved in water before the plant can make use of it as food.

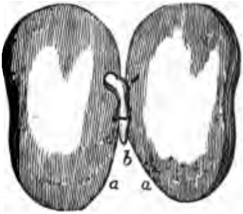


FIG. 1.—Seed of Bean opened. *a, a,* Seed-leaves; *b,* Embryo or young plant.

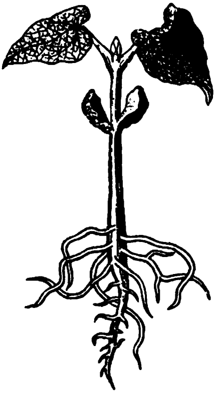


FIG. 2.—Bean with Seed-leaves shrivelled up.

It is the same with grains of wheat, and indeed with all seeds. The young plant, or *embryo*, as it is called, is generally only a small part of the entire seed; the rest of which consists of a store of food, prepared by the plant on which the seed grew, and laid up in the seed as a supply for the embryo until its own leaves and root shall appear.

This food laid up in the seed consists of a substance called *albumen*, which has almost exactly the same composition as white of egg, being made of the four elements carbon, hydrogen, oxygen, and nitrogen. By keeping some seeds moist and warm, while we allow others to become dry, we shall see what a difference this makes to the growth of the young plant. It is the same in the soil: we may sow seeds, but if the soil is dry they will not grow. The food laid up in the seed for the young plant cannot be used if there is no water to dissolve it. As soon as a shower of rain falls, the tiny stems and leaves appear above the ground, while the root strikes downwards: this is because the rain-water has dissolved the albumen in the seed, and the little plant or embryo has sucked it in and used it to make its first growth.

4. An Egg and a Seed.—If we examine an egg, it may help us to understand the nature of a seed; for we may say that a seed is an egg formed by a plant, or that an egg is a seed formed by an animal. An egg has a covering to protect its soft contents from harm, and a seed also has a tough coat. Within the egg lies a tiny spot, or germ, or embryo, surrounded by a store of albumen intended to nourish it until the little chick has grown so large that it is able to seek food for itself. There is just the same arrangement in every seed. When the chick cracks the shell and steps forth perfectly formed, with bones and flesh and feathers, it leaves an *empty*

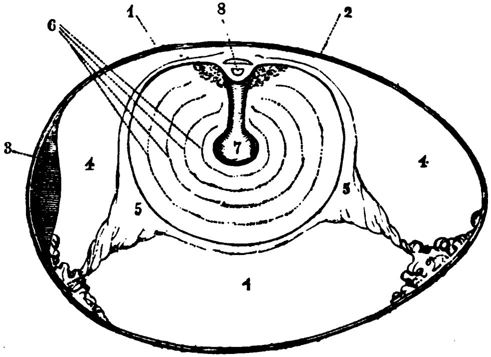


FIG. 3.—SECTION OF EGG.

1. Shell. 2. External layer of shell membrane. 3. Air chamber. 4. Albumen. 5. Twisted cords. 6. Yellow yolk. 7. White yolk. 8. Germ or embryo of the young chick.

shell behind it, for the albumen has all been used to make the chick. So, too, when the little seedling sends out its first rootlets and puts forth its first green leaves, the seed shrivels and looks like an empty little bag. All its store of albumen has been yielded up to form the tissues of the growing plant.

II.—PLANT-FOOD IN THE SOIL.

5. Sources of Plant-Food—6. Composition of the Soil—7. Composition of Plants —8. How to make some Plant-Food—9. Organic Plant-Food.

5. Sources of Plant-Food.—Though the growth of the embryo empties the seed, and the seed is shrivelled up, the plant goes on growing, and becomes perhaps a mighty tree, rising high into the air, bearing great branches and countless leaves, and with roots stretching far and wide. Now it is one of the first principles of science that we cannot make something out of nothing. Where, then, does the plant get the material out of which it constructs its leaves and branches, its stem, root, flowers, and fruits, after it has used up the supply of food afforded by the seed?

We usually consider the root as the part of the plant by which its food, or nourishment, is taken in. We naturally look, therefore, to the *soil* as one source of plant-food; and in this we are quite right: the soil does supply a considerable quantity of material to the growing plant. But the plant feeds also on the *air* which surrounds it. If we place a plant growing in a pot underneath a glass shade, and then, by means of an air-pump, draw out all the air from inside the cover or shade, the plant will wither away and die in a very short time. It is very important to know that plants live partly on food obtained from the soil and partly on food obtained from the air.

6. Composition of the Soil.—The soil is made, for the most part, of mineral or inorganic matter—of matter that has no life, and never had any. All fertile soils, however, contain also some organic substances, which may form as much as one-tenth of the weight of good soil. This organic matter is of a dark or black colour, and is derived from decaying animal or vegetable matter: it is often called *humus.* Now we must not think that the whole of the soil is ready to act as plant-food. The soil as a whole is useful as a support for the plant, enabling it to fix itself so that the winds cannot blow it from one place to another; but only a very small portion of the soil is capable of acting as plant-food.

The reason of this is, that very little of the earth or soil is in a state in which it can be dissolved by water, or even by water containing weak acids. That is quite right, and very fortunate, since, if the whole of the soil were soluble, it would soon be washed away by rain and rivers; the face of the country would be left bare, and we should have no soil left. That portion of the soil which is ready for use as plant-food is called the *active* portion of the soil, while the remaining and greater part is said to be *dormant.* In the first volume of this book we have shown that it is quite possible, by thoroughly breaking up the soil, by draining it, and by exposing it to the air, to convert year by year some of the dormant matter into the active state. Doing this well and thoroughly constitutes one of the great differences between good farming and bad farming.

7. Composition of Plants.—By taking to pieces any machine, it is possible for a clever mechanic to find out of what parts it is made, and how it works. Now a chemist can take to pieces, or *analyze*, a plant, and tell us the substances of which it is composed. If we wish to know what kind of food to offer to plants, it is clearly very important to find out their composition. If a machine can only be made of steel, it would be no use to supply the mechanic with brass, in order that he might construct one for us. It is just the same with plants: they are made of certain kinds of matter, and they require those kinds as food. If we offer them other substances, they cannot make use of them; and they tell us this by the way in which they quickly droop and die when deprived of their proper food.

Plants are composed of inorganic and of organic substances. These can be separated from each other by burning. The organic matters then pass away as smoke, or gas, and mingle with the air; the inorganic part of the plant remains, and forms the ash. By analyzing the ashes of plants, chemists find that they contain the following inorganic compounds:—

Silica.
Phosphoric acid.
Carbonic acid.
Sulphuric acid.
Chlorine.
Lime.
Potash.
Soda.
Magnesia.
Oxide of iron.

If plants are composed of all these substances, it seems certain that they will require them all in their food. Plant-food must therefore be made of many things: it is not a simple substance, but a complex compound.

The organic part of plants, which is driven away by burning, consists of a solid element called carbon, and of the three gases known as hydrogen, oxygen, and nitrogen.

If we supply the young plant with all the substances, organic and inorganic, named above, in such a state that they are soluble in water; if we also keep it moderately warm, and let it have plenty of air and sunshine, it will use these materials to build itself up into a large and strong plant—it will become heavier day by day, and finally it will put forth its flowers and ripen its fruit.

8. How to make some Plant-Food.—When plants grow in the soil, it is difficult to tell exactly what they are feeding on. But it is possible to grow a plant in such a way that we know exactly what it has to eat, because we place it so that it cannot get anything except what we choose to give it. Just as a mother or a nurse can prepare food for children, so can we prepare food for plants which will contain all that is necessary for their healthy growth.

Pure sand is composed only of silica, a substance which in that state is quite insoluble in water, and is then of no use as plant-food. We can use it, however, as a support for the plant—as a bed for a plant to grow in. If we place an acorn in some clean sand filling a flower-pot, and then keep the pot moist and warm, we shall soon see the acorn splitting open, after which the young plant within sends a little root downwards, while a stem, bearing two or more green leaves, rises up to seek air and light. If we still supply the plant with nothing but pure water, it will fade and soon die; but if we frequently give it some of the following mixture, or plant-food, it will grow well and vigorously.

Place a small bone on a clear fire, and allow it to remain until the "gristle" has burnt away; remove it, and grind it to a powder. To 300 grains weight of the powdered burnt bone add half a pint of water, and then some nitric acid, until the bone is dissolved (a gentle heat will assist in this); dissolve a little carbonate of potash in water, and add it to the dissolved bone until the mixture looks rather thick or turbid; add also of nitrate of potash 170 grains, of sulphate of magnesia 107 grains, of chloride of potassium 46 grains, and of water enough to make the whole up to a quart. We now have a strong or concentrated solution of mineral substances, which we shall find to be a most valuable plant-food. To use it we must add two tablespoonfuls of the strong solution to one quart of pure water, to which add also one drop of a solution of perchloride of iron. In this way the quart of concentrated plant-food will yield ten gallons of dilute plant-food fit for use. If we keep the sand in which the acorn is growing moist with this diluted plant-food, we shall find the young oak tree grow rapidly. Instead of growing a plant in sand, it is quite possible to grow it in a jar or bottle, suspending the plant by passing it through a hole in a cork, and filling the bottle once a week with the dilute mixture. The outside of the bottle should be painted over or covered with paper to keep out the light, since the roots of plants like to feed in the dark.

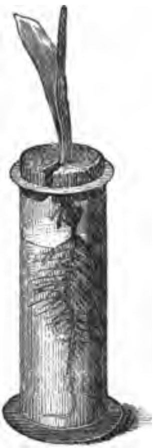


FIG. 4.
Plant growing in Jar of Water.

9. Organic Plant-Food.—By experiments like these we learn that plants take in from the soil, through their roots, mineral matters dissolved in water. But whence do they obtain the organic substances, the carbon, the hydrogen, the oxygen, and the nitrogen, of which they contain so much? The water can yield hydrogen and oxygen, for it is a compound of these two elements. The carbon we believe the plant obtains chiefly from the air, for the air contains a gas called carbonic acid, which is formed of carbon and oxygen. The nitrogen is now believed to be supplied principally by substances contained in or passing through the soil.

III.—THE STRUCTURE OF PLANTS.

10. The Study of Botany—11. The Parts of a Plant—12. The Age of Plants.

10. The Study of Botany.—It would be a good thing if every farmer and every farm-labourer understood a little of the science called botany. This is the science which tries to teach us about plants. Students of botany endeavour to find out of what parts or organs a plant is made, what is the nature and what is the object of each organ, and how it does its work. To farm successfully, we must study the plants which form our crops, just as a doctor studies his patients, or as a schoolmaster studies the characters of the boys in his school. We must try to learn what plants like, and what they dislike; how they feed, and on what they feed; how they are affected by the weather and by insects; and numerous other facts, some of which can be learned from books, but others only by close and careful watching of the plants themselves, or by observation of them under the microscope.

11. The Parts of a Plant.—In examining a plant carefully we may distinguish the following parts:—

1. The ascending axis or stem. 2. The descending axis or root. 3. The root-hairs or fibrils. 4.

The branches. 5. The leaves. 6. The flower. 7. The fruit, containing a seed or seeds.

• Each of these parts or organs has a special work to do. The STEM supports the branches and the leaves, and furnishes a channel by which the liquid plant-food may pass from one part of the plant to another. It is also called the *ascending axis* of the plant, because it rises up into the air.

The ROOT or descending axis grows downwards, forcing its way into the soil, and so serving to fix the plant firmly in the ground. It sometimes runs straight down in a thick mass, like the root of a carrot or a dandelion: it is then called a *tap-root.*

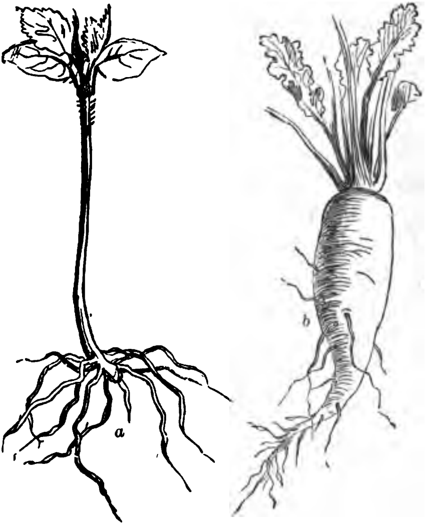


FIG. 5.—FIBROUS ROOT (*a*) AND TAP-ROOT (*b*).

Sometimes the root divides into a great many threads, like those of grasses: then it is called a *fibrous root.*

If we carefully wash the root of a plant, we shall see that it is covered with a great many delicate ROOT-HAIRS or FIBRILS; it is through these that the plant-food from the soil enters the plant. It is difficult or impossible to take up a plant without breaking off a great many of these fibrils, which is one reason why so many plants die when transplanted.

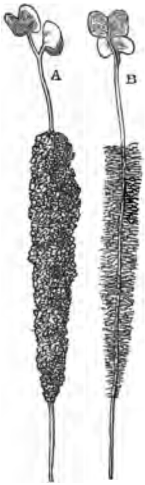


FIG. 6.—Root-Hairs.

A, Young plant with soil adhering to the root. B, The same after being washed, showing the root-hairs or fibrils.

The BRANCHES bear the leaves, and by the manner in which they spread out they expose the leaves to the action of sunlight, air, and rain.

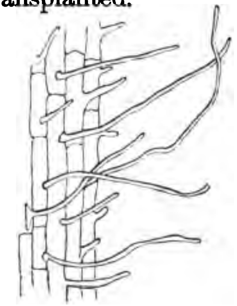


FIG. 7.—Root-Hairs of Barley Magnified.

The LEAVES enable the plant to feed on a part of the air. Their under surfaces are covered with little holes or pores, through which carbonic acid gas (from the air) is taken *in*, while watery vapour and oxygen are allowed to pass *out.*

The FLOWER is easily distinguished in such plants as the rose or buttercup, in which it is large and brightly coloured; but grasses, too, and indeed all the plants which form our crops, have flowers. We

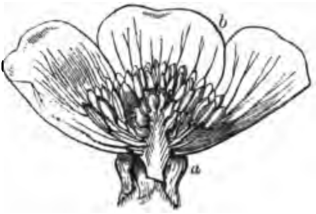


Fig. 8.—Buttercup Flower.
a, Sepal; *b*, Petal.

often do not notice them, because they are small, and green in colour. If we pick a buttercup, we shall notice on the outside of each flower the small, greenish-yellow *sepals* (five in number) which form the *calyx*. Then come five large bright-yellow *petals*, constituting what is called the *corolla*. Inside this we have the *stamens*, looking like little pins with yellow heads. Lastly, in the centre of the flower, are some green bodies called *carpels*, which together form the portion of the flower called the *pistil*. Every part of the flower has its use. The calyx protected the rest of the flower, when it was a bud, from cold and wet. The gaily-coloured corolla attracts insects to visit the flower. The stamens form a yellow dust called *pollen*, and when this pollen is placed on the pistil it makes the carpels swell and form seeds. In many plants the pollen is carried from the stamens of one flower to

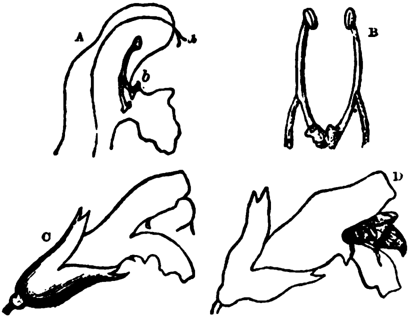


Fig. 9.—Sage Fertilization.
A, Section of the flower of the sage, showing the forked pistil at *a*, and the stamens at *b*. B, Stamens of sage-flower. C, Side-view of flower of sage. D, Insect entering flower.

the pistil of another by insects. Such plants consequently have large and bright flowers, which the insects may see a long way off. These flowers also form a sweet stuff called nectar, to reward the insects for their good work. In the grasses, as wheat, etc., it is the wind that carries the pollen about, so that these plants do not require large or coloured flowers. For this reason it is important to have gentle breezes when the wheat is in flower, otherwise the pollen will not be properly distributed, and the full number of seeds cannot be formed.

The FRUIT is formed by the ripening of the pistil. Thus the ears are the fruit of the wheat plant, nuts are the fruit of the hazel tree, pods are the fruit of the bean or pea, the acorn is the fruit of the oak, and so on. Within the fruit we find a seed or seeds. In the apple, orange, etc., the seeds are imbedded in a soft juicy substance, while in nuts the seed (or kernel) is surrounded by a hard shell.

12. The Age of Plants.—Many plants live for but a single season or year. These are called *annuals* (from the Latin *annus*, a year). Their seeds begin to sprout or germinate in the spring; they flower in summer; their fruit forms and their seed ripens in the autumn, and then the plant quickly dies and decays, its brief life being ended. The wheat plant is a good example of an *annual*.

Other plants are called *biennials* (Latin *bi*, two), because their life extends over two seasons or years. In the first season they form their root, stem, leaves, and branches; and generally the root is large, thick, and fleshy. In the second year they flower and produce seed, using up, in the act of doing this, the nourishment which was laid up in the root. As examples of such plants, we may name the carrot, beet, cabbage, and turnip. When crops of these biennials are grown by the farmer, he does not allow them to remain two seasons in the ground, but takes them up at the end of the first year, and appropriates to his own use the material stored up in the roots.

Still other plants are called *perennials* (Latin *perennis*, lasting for many years), because they go on growing year after year, some existing for three or four years, and others, as the oak, for several centuries. These long-lived plants have generally woody stems, which yearly increase in thickness.

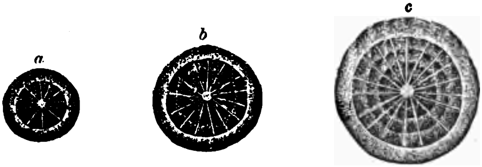


FIG. 10.—Sections of Stems of Oak Trees at the end of first, second, and third years of growth, showing one, two, and three rings respectively.

a, One-year old oak. *b*, Two-year old oak. *c*, Three-year old oak.

By looking at the trunk of a tree which has been cut down, we can often tell its age by counting the number of circles or rings in the wood, each ring representing one year's growth.

IV.—HOW PLANTS FEED.

13. Absorption of Food—14. Feeding Organs of Plants—15. Cultivation permits the Roots to seek for Food—16. Functions of Leaves—17. Leaves take Carbonic Acid Gas from the Air—18. Plants take Ammonia from the Air—19. Leaves as breathing Organs—20. The Sap.

13. Absorption of Food.—Generally speaking, it is easy enough to see how animals take their food. They chew it, and mix it with saliva in their mouths; thence it passes into the stomach, where it is dissolved or liquefied; then it soaks through the sides of the stomach, and enters the blood-vessels, in which it is carried with the blood to all parts of the body. Cases have been known where animals—human beings, for example—could not for a time swallow any food. It has been proved that if a baby suffering in this way be placed in a bath of beef-tea, some of the nourishing fluid soaks in through the skin. Delicate children are often rubbed with oil, and are fattened by a part of the oil passing through the skin. Sailors, too, when shipwrecked and without any fresh water to drink, have in part relieved their thirst by bathing in the salt water of the ocean. A portion of the sea-water passes through their skin, while the salt in the same water is, for the most part, kept out. When food is taken through the skin in this way it is said to be *absorbed.*

14. Feeding Organs of Plants.—Plants feed by means of their roots and their leaves. By means of these organs they *absorb* their food. No solid matter can enter a plant; everything must first be *dissolved.* The reason of this is, that solid grains, or particles, would be far too large to pass through the delicate tissues of the root-hairs. But when we dissolve any substance, as sugar or salt, in water, we separate it into tiny portions called *molecules*, which are so small as to be quite invisible, and which can readily pass through any moist bladdery matter or skin. It is an interesting experiment to dissolve common salt in water, fill a small bladder with the solution, and then place the bladder in a jar of fresh water and leave it there for ten minutes. The fresh water in the jar will then be found to have changed to salt water, showing that some of the salt in the bladder has passed out through the sides of the bladder into the water in the jar. If we put salt water into the jar and fresh water into the bladder at starting, the opposite will happen, for the salt will pass inwards. Bladder is an animal substance, but the tissues of

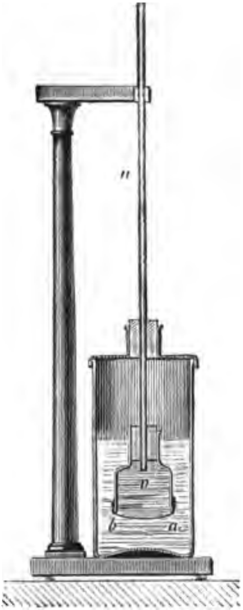


FIG. 11.—Absorption.

a, *b*, Fresh water in jar.
v, Bottle, with skin bottom, containing salt water.
n, Glass tube.

plants act exactly in the same way, and fluids can pass through them quite as easily as water can soak through a bladder. If the soil in which the roots of plants lie is perfectly *dry*, nothing can enter the root-hairs; but as soon as water, containing "plant-food" dissolved in it, enters the soil, some of the liquid passes through the sides of the root-hairs or fibrils, rises up the stem of the plant, and thence proceeds along the branches to the leaves. This is the reason why crops make little or no growth during long periods of dry weather. The plant-food is present in the soil, but since there is no water to dissolve it, it cannot enter the plant. When rain falls, the change is wonderful! The rain-water dissolves the plant-food, and is then eagerly absorbed by the root-hairs and carried to every part of the plant. In this way, especially on dry sandy soils, more growth is made in one week, after showers have fallen, than in three weeks of hot dry weather.

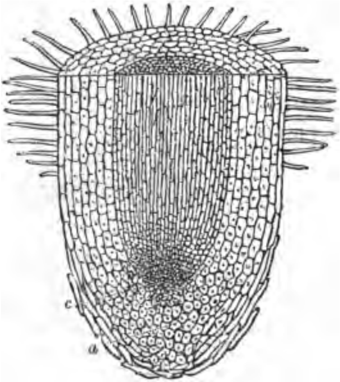


Fig. 12.—Tip of Root-Fibril (magnified) showing the Root-Sheath (*a*, *b*) and Growing-Point (*c*).

15. Cultivation permits the Roots to seek for Food.—We must remember that roots and root-fibrils have to push their way through the soil in search of food. In dry weather the roots of certain plants will go down a depth of two or three feet in search of water. It is most necessary to assist them in this task by making the soil as loose and as open as possible, so that the root-tips may be able easily to force their way. The tip of each root is provided with a kind of cap called the *root-sheath.* As fast as the cells of this cap wear away they are replaced by new cells formed near the end of the root, at a place called the *growing-point.*

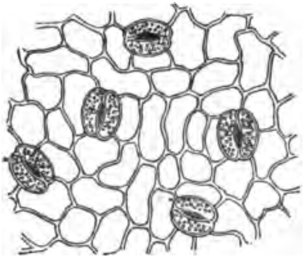


FIG. 13.—Stomates on Leaves.

16. Functions of Leaves.—Leaves are both feeding organs and breathing organs. They not only take in food, but they also rid the plant of matter which in excess would be injurious to it.

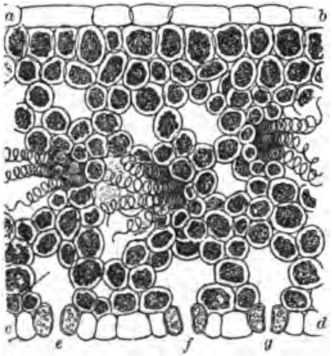


FIG. 14.—Section of a Leaf (highly magnified) showing the Cells and Air-Passages.

a, *b*, Upper surface of leaf. *c*, *d*, Under surface of leaf. *e*, *f*, *g*, Stomates.

Let us first consider the leaf as a feeding organ. When a leaf is examined by means of a good microscope its lower surface is seen to be covered with little holes or pores, or *stomates*, as botanists call them. On the under surface of an apple leaf as many as one hundred thousand of these stomates may be counted. A leaf is not a solid mass of tissue. It is formed of a number of cells; but these cells are only loosely packed together, so that there are little spaces or passages between them. Consequently, when the stomates are open, any gases which enter through them from the air can move about inside the leaf. It is clear that the stomates act very much like little mouths. Hence it has been truly said that there are more mouths on a single tree than are possessed by the entire population of Great Britain.

17. Leaves take Carbonic Acid Gas from the Air.—In ten thousand pints of fresh air there are four pints of carbonic acid gas.

It is not difficult to prove the presence of carbonic acid in the air. We must obtain a small piece of quicklime, grind it up in a jug of water, and strain the water through some blotting-paper until it looks quite bright and clear. Pour some of this clear lime-water into a wide tumbler, and allow it to stand on the table for a few minutes. A scum or crust will slowly form on the surface of the lime-water, caused by the combination of the lime in the water with carbonic acid gas from the air.

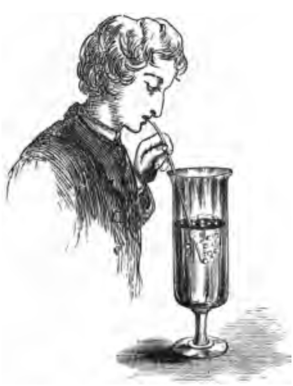


FIG. 15.—Blowing into Lime-Water.

If we now take a clean tobacco-pipe and blow through it so that our breath bubbles through the lime-water, the latter will quickly turn quite white, showing that there is a great deal of carbonic acid gas in the air which we breathe *out*—far more, indeed, than in the fresh air which we breathe *in*. The substance which forms the scum, and which turns the lime-water milky, is called carbonate of lime.

Every animal that breathes, and every candle or gas-jet or fire that burns, *adds carbonic acid gas to the air*. Every green leaf that grows *takes carbonic acid gas out of the air*. In this way the composition of the atmosphere is kept pure and unchanged.

During the daytime, while the sun is shining, and while the stomates are open, carbonic acid gas is continually entering the leaves of plants. Once inside the leaf, a great change takes place: the carbon is separated from the oxygen; the former substance is used by the plant, while the oxygen is returned to the air. A chemist would express the matter in this way:—

$$\underset{\text{Carbonic acid gas}}{CO_2} \quad \underset{\text{is decomposed into}}{=} \quad \underset{\text{carbon and oxygen.}}{C + O_2.}$$

This process does not go on in the dark; nor could it take place without the action of the green colouring substance in the leaf, called *chlorophyll* by botanists. Dr. Siemens has lately made plants to grow by night as well as by day, by using a powerful electric light, which shone on the plants during the night. By this means he succeeded in ripening strawberries, melons, etc., in a very short time.

18. Plants take Ammonia from the Air.—The atmosphere contains a little—a very little—of the compound gas called *ammonia;* perhaps one million pints of air may contain one pint of ammonia. The composition of this gaseous substance is one part of nitrogen to three parts of hydrogen, so that it may be written NH_3. Now, as the winds blow, a great quantity of air passes over each plant daily, and the leaves take in a little of the ammonia from the air through their stomates. Nitrogen is one of the most important of the elements required by plants; but, strange to say, plants cannot feed on pure nitrogen. If they could, they would not have far to seek for their food, for pure nitrogen gas forms four-fifths of the air.

In some cases plants also take in water and water-vapour from the air through the pores in their leaves. The great supply of water, however, enters the plant by the root.

19. Leaves as breathing Organs.—When animals breathe, they take oxygen out of the air, while they exhale or give off carbonic acid gas. When a number of people live in a small, badly-ventilated room, the air is soon made unfit to be breathed by the carbonic acid gas which is continually streaming out of the mouth of every human being present. We have seen that plants affect the air in just the opposite manner. They *take in* the carbonic acid gas, and, separating the carbon from the oxygen, they *breathe out* the latter element. Thus plants tend to purify the air.

This may be beautifully shown by taking a number of fresh green leaves, as those of thyme or water-cress, placing them in a bottle full of spring-water, and then turning the bottle (taking care to let no air get in) upside down in a basin of water. Now leave the bottle exposed to bright sunlight for a few hours, and the leaves will be seen to be covered with bubbles of oxygen gas, of which a quantity will also be found at the top of the bottle. This oxygen gas will relight a glowing match. It has been produced by the action of the leaves on the carbonic acid gas which is always contained in spring-water.

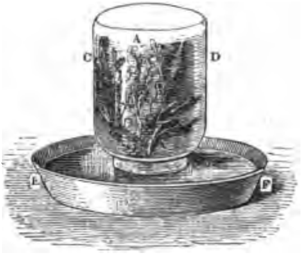


FIG. 16.—Green Leaves producing Oxygen.

E, F, Large Saucer containing water. C, D, Glass round-topped vessel, containing leaves in water, turned upside down upon E, F. A, Space at top of vessel containing oxygen gas from leaves.

But plants also breathe out through their stomates great quantities of water-vapour. Generally speaking, plants take in, through their roots, more water than they require, and the excess passes away through the tiny holes in their leaves. It is wonderful to notice how the pores or stomates change in size according to the state of the weather — opening widely when the air is moist, and closing up when the air is hot and dry and the plant is likely to need all the water it has within it.

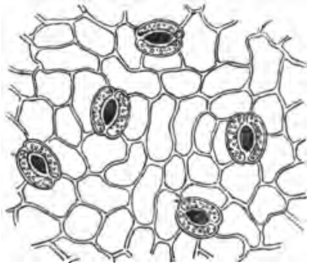


FIG. 17.—Stomates on Leaves in Damp Weather.

20. The Sap.—The fluid which flows through plants is called the *sap*. The raw sap consists of much water, with plant-food dissolved in it, which has entered the plant through its roots. This raw sap rises through the outer part of the stem into the leaves, and there it is manufactured into various substances, of which the following are the principal:—

COMPOUNDS FORMED IN THE LEAVES OF PLANTS.

I. NON-NITROGENOUS SUBSTANCES. Composed chiefly of carbon, hydrogen, and oxygen.	Starch. Gum. Sugar. Cellulose. Oil.
II. NITROGENOUS SUBSTANCES. Composed chiefly of carbon, hydrogen, oxygen, and nitrogen.	Albumen. Gluten. Legumin.

These substances are carried out of the leaves in the altered sap, and are distributed to every part of the plant, helping to form and to fill new cells; aiding everywhere, in fact, in the life of the plant.

V.—HOW PLANTS GROW.

21. Composition of Plants—22. Carbon in Plants—23. The Growth of a Crop of Wheat—24. The Wheat-Plant finds Food in the Seed—25. The Wheat-Plant finds Food in the Soil and in the Air—26. Reaping the Crop.

21. Composition of Plants.—We see, then, that plants are composed of organic and of inorganic matter. The latter is derived entirely from the soil; the former is derived partly from the air and partly from the soil.

It is easy to separate the mineral or inorganic part of plants from the organic part. It is done whenever we burn any vegetable matter. Suppose that we burn 100 lbs. weight of dry wheat (straw and corn together), we shall have left 4½ lbs. of a whitish ash, which is called the *inorganic* part of the wheat plant. The substances of which this is composed we have already noted. (See page 14.) But 95½ lbs. have escaped into the air, passing away as gases. This is the organic matter of the plant. We see that the latter constitutes by far the greater portion of the plant. The inorganic part gives strength to the tissues of the plant. In straw, for instance, it is the silica which makes the stem so hard and bright. It may, therefore, be said to play, in the plant the part of the skeleton or bones in animals.

We may also note the contrast between the soil and the plant as to their composition. The *soil* contains much *inorganic* matter, the plant but little. In the soil there is little *organic* matter, in the *plant* there is much.

22. Carbon in Plants.—The organic part of a plant consists almost entirely of the four elements—carbon, hydrogen, oxygen, and nitrogen. The three latter are gases, while carbon is a black solid. When a plant is burned in a confined space, so that air cannot freely get to it, the hydrogen, oxygen, and nitrogen are driven away by the heat; but the carbon remains, and the half-burned wood is then called *charcoal*. This charcoal consists of carbon, together with the ash or mineral part of the plant. By continuing the heat, and admitting more air, we can get the carbon to burn away, and then only the ash will remain. To illustrate this by an experiment, take a match, light it, and place it in a glass tube (the narrow neck of a bottle will do): a little stick of charcoal will remain. This may be burned in the open air, and the only thing then left will be a very little whitish ash—the inorganic part of the wood.

FIG. 18. Burning wood in glass tube

Carbon forms about *one-half the weight* of dry vegetable matter. Thus 100 lbs. of dry wood yield about 50 lbs. of charcoal. It is clear, then, that carbon forms a much larger portion of the plant than any other element, and that plants will need a large supply of it, in some form or other, if they are to grow vigorously and well. The chief source from which plants obtain their carbon is carbonic acid, either absorbed by the leaves from the air, or entering the root dissolved in water.

23. The Growth of a Crop of Wheat.—Let us now consider the growth of a crop of some kind of plant, and see from whence it obtains the nourishment—the food—by which it is enabled to grow. We shall suppose the soil to be fertile, containing all the inorganic materials needed by the plant. The situation, too, shall be a favourable one, where plenty of fresh air blows daily over the leaves; while bright sunshine and frequent showers shall aid in the work.

Let the crop be wheat, and the extent of ground one hundred acres. This would require about one bushel of seed-corn per acre, which we shall suppose to be sown early in March, the seeds being covered with soil to the depth of about one inch.

24. The Wheat Plant finds Food in the Seed.—Lying in the moist soil, the tiny plant coiled up within each seed begins to grow. The water in the soil soaks through the covering of the seed and dissolves some of the albumen. This albumen is eagerly absorbed by the embryo or young plant, and the result is soon seen in the growth of the latter. In a few days the young wheat-plant has become so large that it bursts the covering of the seed, and its little white stem tries to find its way upwards, seeking the light; while equally white and tender rootlets find their way downwards and sideways into the soil. Still the albumen in the seed is not quite used up, and as the rest of it is dissolved, it feeds the little plant, and enables it to rise above the surface of the soil, putting out a slender green leaf, while the rootlets multiply greatly.

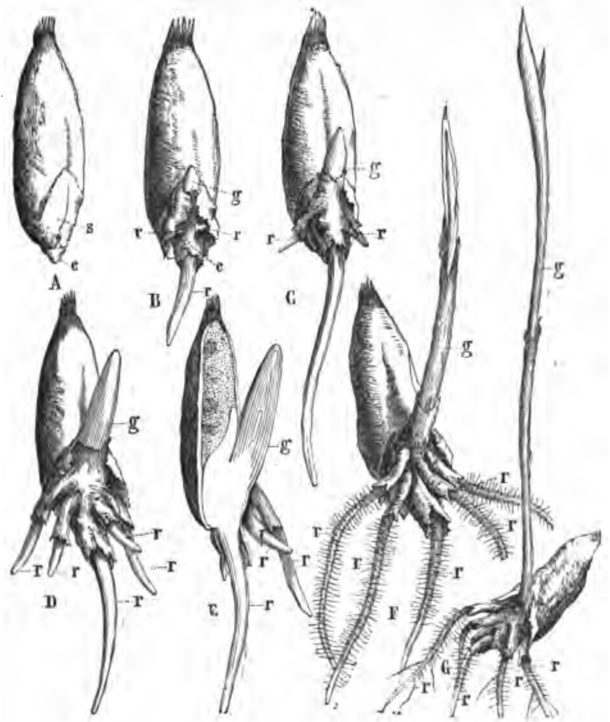


Fig. 19.—Germination of Wheat.

A, Seed: *s*, point at which the stem will appear; *c*, appearance of the sheath which covers the root. B, *r*, rootlet; *r*, *r*, rootlets still enclosed in their sheaths; *g*, the stem. C, D, Showing the same parts as in B in more advanced stages. E, Section of D, showing the albumen. F, G, Lengthening of the stem, and appearance of the green leaf.

25. The Wheat-Plant finds Food in the Soil and in the Air.—By this time the supply of food laid up in the seed—the mother's milk, as it were, placed there by the parent plant—has been quite used up. But now, provided with green leaves and with roots, the wheat-plant is able to work for and to feed itself. The rootlets push through the soil in search of plant-food. Mineral and organic substances, dissolved in water, enter through the soft moist sides of the smallest roots, and rise up the stem into the leaves. The leaves themselves are not idle. All day long they are absorbing carbonic acid from the air by means of their pores: within the cells of the leaves manufacturing processes are also going on, by which starch, gum, sugar, albumen, etc., are being formed out of the plant-food taken in by both leaves and roots.

In July the wheat flowers, and as soon as this process is completed the seed begins to be formed. In August we note a change of colour—the green tints disappear and the whole plant becomes yellow.

26. Reaping the Crop.—Now the farmer steps in. He reaps the crop, thrashes it, and tries to find out what he has gained. The result will differ widely according to the nature of the soil, the seed, etc.; but if an average crop has been obtained, the farmer will find himself in possession of, say, 25 bushels of corn and 3,000 lbs. of straw from every acre. One bushel of seed-corn per acre was put into the soil: 25 bushels are taken out; and in addition to this there is the weight of the straw (3,000 lbs.), and of the roots which remain in the soil.

Now let us suppose that we take the entire crop of corn and straw from the one hundred acres and dry it thoroughly in a large oven. Although the vegetable materials might appear quite dry before being heated, we should find that the heat would drive off a quantity of water-vapour.

Applying more heat, we should next send away the gases known as hydrogen, oxygen, and nitrogen ; the corn and straw would blacken, and would now weigh about half what they did before they were heated at all.

Continuing the heat, and admitting air freely, the black mass of carbon would also burn away; and finally there would remain 17,500 lbs. (or about 8 tons) of a whitish ash—the mineral matter contained in the crop.

Here, in the ash, we see the inorganic substances removed from the soil of the hundred acres by the wheat crop. The next thing is to inquire of what substances the 17,500 lbs. of mineral matter are composed. This can be done by a careful chemical analysis. The result is given in the following table.

Table showing the Mineral Matter removed from 100 Acres of Land by an ordinary Crop of Wheat.

	In the Corn. lbs.	In the Straw. lbs.	Total.
Potash	749	1,821	2,570
Soda	97	90	187
Magnesia	307	411	718
Lime	85	934	1,019
Phosphoric Acid	1,147	815	1,962
Sulphuric Acid	8	582	590
Silica	84	10,182	10,266
Per-oxide of Iron	20	132	152
Common Salt	3	33	36
	2,500	15,000	17,500

This table shows us that the wheat-plant requires at least nine mineral substances to exist in a soluble state—that is, as plant-food—in the soil. If any one of these substances be wanting, no wheat crop can be got from that soil. If there be *only a little* of one or two of these nine compounds, only a *poor* wheat crop can be obtained.

To get *good* wheat-crops we must have an abundance of every one of these nine inorganic substances. Not that the wheat-plant takes an equal quantity of each substance. We see that silica and potash are especially needed, and this is one reason why wheat grows well on stiff clays, for a clay soil generally contains a store of soluble silica. We may call wheat a *silica plant*, since it requires so much of that substance.

VI.—HOW CROPS EXHAUST THE SOIL.

27. Effect on the Soil of the continued Growth of Wheat—28. Mineral Substances removed from the Soil by a Clover Crop—29. Mineral Substances removed from the Soil by a Turnip Crop—30. Why Wheat is considered so exhausting to the Soil—31. Mineral Substances removed from the Soil by a Bean Crop.

27. Effect on the Soil of the continued Growth of Wheat.—If a single crop of wheat removes mineral plant-food from the soil at the rate of 175 lbs. per acre, it is quite certain that the land cannot be so rich or so well able to support the growth of another crop as it was before the first crop of wheat was sown in it.

If we sow and reap a *second* crop of wheat immediately after the first one has been gathered in, we shall take still more mineral matter from the soil; and if we go on doing this year after year, without returning anything to the soil, the land will become so poor that it will be unable to yield crops of wheat at all. The experiment has actually been tried by Sir J. B. Lawes on his farm at Rothamstead, in Hertfordshire, which he keeps, not for profit, but to advance the science of agriculture. On this farm wheat has been grown on the same piece of unmanured ground for about thirty years. At first the produce was 23 bushels of corn and 24 cwt. of straw per acre; it has now gone down to 4½ bushels of corn and 6¾ cwt. of straw per acre. It was a good, rich loamy soil to begin with, or it would not have done even so well as this.

We may notice, however, that if we were to *return the straw* of every crop to the ground, this would give back to the soil the greater portion of the mineral matter used up by the crop; for of the 17,500 lbs. contained in the wheat crop (see page 38) 15,000 lbs. were present in the straw, and only 2,500 lbs. in the corn.

28. Mineral Substances removed from the Soil by a Clover Crop.—But do all our crops remove the *same* substances from the soil? To answer this question we must analyze the ashes of other plants. Let us ask, What mineral matters would be removed by a crop of clover from the soil of a hundred acres of ordinary land?

Table showing the Mineral Matter removed from 100 Acres of Land by an ordinary Crop of Clover.

	lbs.
Potash	5,200
Soda	700
Magnesia	3,500
Lime	11,100
Phosphoric Acid	2,000
Sulphuric Acid	1,300
Silica	1,000
Per-oxide of Iron	300
Common Salt	800
	25,900

The total weight of the green crop may be reckoned at 200 tons, being 2 tons per acre. The mineral matter contained in this would weigh 25,900 lbs., or 11½ tons. From this it is clear that clover exhausts the soil more than wheat. We often hear of a soil becoming "clover-sick,"—that is, being in such a condition that clover will not grow well in it. The reason is clear: the clover has *used up* the plant-food needful to it in the soil. We see, however, that clover does not prefer exactly the same substances as wheat. The wheat used ten times as much silica as lime; the clover takes ten times as much lime as silica, so that we may call clover a *lime plant.* Considering this, we may understand that it is possible that land which was "clover-sick" might still grow a fair crop of wheat; or if, perchance, the soil does not contain enough silica for wheat, yet clover may grow well in it.

29. Mineral Substances removed from the Soil by a Turnip Crop.—An average crop of turnips weighs 26 tons per acre, so that one hundred acres would produce a total weight of 2,600 tons. The bulbs would weigh 2,000 tons and the tops 600 tons. If we burned all this weight of vegetable matter, we should have left 60,000 lbs., or nearly 27 tons, of ash, representing mineral matters removed from the soil by the growing crop. This great weight proves clearly that turnips exhaust the soil far more rapidly than either clover or wheat. They grow very rapidly, and their roots and leaves must work with great energy to provide the turnip-plant with the large amount of plant-food which it requires.

Table showing the Mineral Matter removed from 100 Acres of Land by an ordinary Turnip Crop.

	In the Bulbs. lbs.	In the Tops. lbs.	Total.
Potash	12,800	7,600	20,400
Soda	2,300	1,630	3,930
Magnesia	1,230	930	2,160
Lime	3,800	6,990	10,790
Phosphoric Acid	3,111	2,820	5,931
Sulphuric Acid	4,300	3,660	7,960
Silica	1,170	260	1,430
Per-oxide of Iron	389	260	649
Common Salt	2,900	3,850	6,750
	32,000	28,000	60,000

The turnip may well be termed a *potash plant*, for it requires twice as much of this substance as of any other mineral.

30. Why Wheat is considered so exhausting to the Soil.—These figures show clearly that either clover or turnips are, during their time of growth, far more exhausting to the land than wheat. And yet it is generally considered that wheat is a crop which cannot be taken from a field two years running without doing harm to the soil. In fact, when a landlord lets a farm to a tenant, he often makes him agree not to take two white straw crops in succession off the land. The reason really is that in a wheat crop all the mineral matter in the corn is *lost to the land*. It is sold off the farm, and the soil sees it no more. But in root or hay crops nearly all the mineral matter is *returned to the land;* for these crops are used on the farm, and the manure produced by the animals eating the crops is given back to the soil. In this way the soil recovers most of the mineral matter which it lent to the clover or to the turnip crop.

31. Mineral Substances removed from the Soil by a Bean Crop.—An average crop of beans will yield 25 bushels of corn and 2,800 lbs. of straw per acre. This is about the same weight of produce as wheat, but it contains very different proportions of mineral matter.

Table showing the Mineral Matter removed from 100 Acres of Land by an ordinary Crop of Beans.

	In the Corn. lbs.	In the Straw. lbs.	Total.
Potash	2,240	8,917	11,157
Soda	668	269	937
Magnesia	503	1,124	1,627
Lime	363	3,358	3,721
Phosphoric Acid	2,368	1,250	3,618
Sulphuric Acid	61	183	244
Silica	72	1,184	1,256
Per-oxide of Iron	35	......	35
Common Salt	90	715	805
	6,400	17,000	23,400

We see that a bean crop will take 23,400 lbs., or 10½ tons, of mineral matter from the soil of a hundred-acre field. The greater part of this, however, will lie in the bean-straw, and if this is returned to the soil it will make up for two-thirds of the loss. From the large amount of phosphoric acid and of lime which a bean crop robs the soil of, it is clear that it will require much phosphate of lime in the soil; the bean may therefore be termed a *phosphate plant.*

VII.—ROTATION OF CROPS.

32. Comparison of Crops—33. The Rotation of Crops—34. Cleaning the Land—35. Systems of Rotation—36. Rotation on Clayey Soils—37. General Advantages of Rotation—38. Rotation alone cannot prevent the Exhaustion of the Soil.

32. Comparison of Crops.—We have now learned that all crops exhaust the soil in which they grow, but they do not all exhaust it equally. Moreover, some plants require a large quantity of one mineral in their food, while others desire quite a different substance. We may classify our crops according to the substances which they especially need:—

SILICA PLANTS	Oats. Wheat. Barley. Rye.
LIME PLANTS	Peas. Beans. Clover.
POTASH PLANTS	Potatoes. Beet-root. Turnips.

Although a soil may be so exhausted of one kind of plant-food—say silica—as to be unable to yield a good crop of any plant that required a large amount of that substance, yet it by no means follows that this soil could not grow some other crops which did not need much of the substance in which the soil was deficient. If the soil of a field be poor in soluble silica, it will not give us a good wheat crop; but it may be quite able to grow a good bean crop, since the latter plant requires but little silica. The discovery of this fact, long ago, led to the system of changing the crop yearly in every field. This is called the *rotation of crops*.

33. **The Rotation of Crops.**—What are the principles which should guide us in fixing the order in which our crops shall be grown?

(1.) *One crop should not follow another which requires the same kind of food.* A silica plant should not succeed a silica plant, nor a potash crop be grown in the next season after that in which a potash crop has been reaped. On the contrary, plants which require the same kind of food must be separated by as long a time as possible. In the interval the soil will have time to recruit itself. Much of the required mineral may exist in the soil in the dormant state, and if this be given time, some of it will change into the active condition.

(2.) *Regard should be had to the mode of rooting of plants.* Thus barley-roots seek for food chiefly in the surface layer of the soil; clover strikes down deeply, and gets its plant-food from quite another layer. It is found that clover *brings up* plant-food from below, and stores it up in a matted net-work of root-fibres near the surface. When wheat follows clover, it finds in this mass of roots a capital store of plant-food ready for use. It is a well-known fact that a good wheat crop is almost sure to follow a good clover crop.

34. Cleaning the Land.—Another advantage of the rotation of crops is that it enables the land to be thoroughly and systematically cleaned. After frequent corn crops weeds are sure to be plentiful, for these crops stand long on the ground, and they are closely sown. By taking a root crop after a corn crop, we obtain the following advantages:—(1.) Time to cultivate the land thoroughly; the corn crop being reaped in September, while the root crop need not be sown till the following June. (2.) The Roots lying wide apart, labourers can hoe the ground between and destroy the weeds. (3.) Roots being consumed on the farm, most of the substances they take from the land are returned to it again in the form of manure; consequently root crops do not exhaust the land so much as corn crops, which are sold and removed from the farm.

35. Systems of Rotation.—On light soils a course of cropping is widely used which is called the *Norfolk Rotation*, because it has been long used in that county. It is as follows:—

First Year	Roots (a potash plant).
Second Year	Barley (a shallow-rooted silica plant).
Third Year	Clover (a lime plant).
Fourth Year	Wheat (a deep-rooted silica plant).

This is the course which would be followed for any given field. In the first year the farmer would plant roots—turnips, for instance—and he would manure his soil well, cultivate it thoroughly, and get it made very clean. In the second year he would sow barley in this field,—a crop which would make a large demand for soluble silica from the soil, but would draw it chiefly from the *upper* part. In the third year clover would be grown. This plant would draw largely on the lime in the *upper* part of the soil, but its mass of fibrous roots would give firmness to the land, and it would probably be eaten off by sheep, in whose excrement the greater part of the mineral matter would be returned to the soil. Lastly, in the fourth year, would come wheat, whose deep roots ought to find a good supply of silica in the *lower* part of the soil.

1st Year.	W Roots.	X Barley.	Y Clover.	Z Wheat.
2nd Year.	W Barley.	X Clover.	Y Wheat.	Z Roots.
3rd Year.	W Clover.	X Wheat.	Y Roots.	Z Barley.
4th Year.	W Wheat.	X Roots.	Y Barley.	Z Clover.

Fig. 20.—Plan showing the "Norfolk" System of Rotation of Crops. The farm is supposed to consist of four fields—w, x, y, and z.

36. Rotation on Clayey Soils.—Good clayey soils contain such an abundance of silica that it is advisable to grow on them two or even three crops of silica plants in the course of a rotation.

A FIVE-YEAR ROTATION FOR A GOOD CLAY SOIL.

First Year	Roots (turnips, swedes, or mangels).
Second Year	Wheat (a deep-rooted silica plant).
Third Year	Barley (a shallow-rooted silica plant).
Fourth Year	Clover (a lime plant).
Fifth Year	Wheat (a deep-rooted silica plant).

	A	B	C	D	E
1st Year.	Roots.	Wheat.	Barley.	Clover.	Wheat.
2nd Year.	Wheat.	Roots.	Clover.	Wheat.	Barley.
3rd Year.	Barley.	Wheat.	Wheat.	Roots.	Clover.
4th Year.	Clover.	Barley.	Roots.	Wheat.	Wheat.
5th Year.	Wheat.	Clover.	Wheat.	Barley.	Roots.

FIG. 21—Plan illustrating a Rotation of Crops suitable for a Clay Soil. The farm is supposed to consist of five fields—A, B, C, D, E; and the Rotation extends over five years.

37. General Advantages of Rotation.—A good system of rotation of crops not only assists in preventing the exhaustion of the soil, by giving it time to *recover itself* after having been heavily taxed by some particular crop, but it is also advantageous in *spreading the farm-work over the entire year*, so that regular employment is found for the farm-labourers. Then it *diminishes the farmer's risks,* since, if the weather is unsuitable for the crops on one part of the farm (as wheat), it may do no harm to the crops in other fields (as roots). A good farmer of course takes care to divide the fields of his entire farm, so that while wheat is growing in one part, roots occupy another, clover another, and so on, according to the system of rotation adopted. If the entire farm were occupied by one crop (as wheat), and the weather proved bad for that crop, then the farmer might be ruined. Besides, at one time of year a great many men would be needed for the work of the farm, and at another time hardly any.

38. **Rotation alone cannot prevent the Exhaustion of the Soil.**—Finally, we may notice that though a good system of rotation of crops may *delay* the exhaustion of the soil, yet it cannot entirely prevent it. How the productiveness of the soil may be maintained, and even increased, we shall try to explain in the succeeding chapters.

VIII.—ACTION OF MANURES.

39. Exhaustion of Virgin Soil—40. How to maintain the Fertility of the Soil—41. Cultivation increases the Supply of Plant-Food in the Soil—42. Cultivation alone is not sufficient—43. Plant-Food must be added to the Soil—44. Definition of a Manure—45. Classification of Manures—46. How to select a Manure—47. How Manures yield a Profit.

39. Exhaustion of Virgin Soil.—It is certain that no soil, however fertile, contains a sufficient amount of plant-food to enable it of itself to furnish the nourishment requisite for large crops year after year. The early settlers in the United States picked out the rich virgin soil, in which no crops had ever been grown by man, and they were surprised at the heavy crops they obtained without the use of any manures. Farmers from England, who had been accustomed to think forty bushels of corn per acre a good crop to get from well-manured land, were surprised when, in the New World, they got fifty-five or sixty bushels per acre without the addition of any fertilizing matter at all. The fact was, the "virgin soil" was very rich in plant-food. This plant-food had been accumulating for many centuries, and it was able to give a splendid supply of nourishment to the wheat. And so matters went on for several years. But, in the course of time, the

American farmers began to find their crops decreasing. They had taken crop after crop from the soil, while they had returned little or nothing to it, and so the store of plant-food was becoming exhausted. Many of these farmers sold their land to newcomers, to whom this fact was unknown, and moved further west to settle again on untilled, unexhausted land, there to repeat the same process. This has been done again and again, until at last nearly all the rich virgin soil of the United States has been brought under cultivation.

40. How to maintain the Fertility of the Soil.—But is it not possible to maintain the fertility of the land, or even to increase it, and at the same time to draw good crops from it every year? Most certainly it is, and the way to do this is to thoroughly cultivate the soil, and at the same time to add to it yearly as much useful material as we take away in our crops, or, if possible, even more.

41. Cultivation increases the Supply of Plant-Food in the Soil.—In the first volume of this book we learned how cultivation increases the fertility of the soil. Only a very small part of the soil is ready, at any given time, to be of use to the plant. Out of 100 lbs. weight of good soil there are perhaps 3 lbs. weight which we may consider as plant-food. This small proportion represents all the portion of the soil which is capable of being dissolved at the time by rain-water: it is called the *active* part of the soil. The other 97 lbs. consist of matter which may in the future be changed into plant-food, but which in its present state is only useful as furnishing a bed in which the plant can firmly fix itself: it is called the *dormant* part of the soil. By good cultivation it is possible, yearly, to convert some of the dormant into active matter. By stirring the soil with the spade or plough, by harrowing and rolling it, by breaking it up and exposing it to air, frost, and rain, we can do much to help the insoluble (or dormant) part of the soil to become soluble (or active).

42. Cultivation alone is not sufficient.—But if we were to do all this in the most perfect manner—using the steam-plough to break up the ground to a depth of several feet, draining the soil well, too, so that air and rain-water would be able to pass freely through it—still we should find, after two or three seasons, a considerable falling off in our crops. The fact is, that vegetables remove from the soil very considerable quantities of the substances out of which they build up their tissues and organs—their roots, stems, leaves, flowers, and fruit. We must also remember that plants need a large *variety* of substances in their food. It is not sufficient to have a great deal of one or two kinds, and little or none of others which are equally necessary. The soil, for instance, may contain plenty of soluble silica, and plenty, perhaps, of lime, yet if it be deficient in potash or in oxide of iron, the crops will be poor. It has come to be a well-understood maxim or rule in agriculture that it is that necessary substance of which the *least amount* is present which determines the degree of fertility of any soil.

43. Plant-Food must be added to the Soil.—The soil may be called the farmer's bank. If we frequently go to our savings-bank and draw out the money belonging to us without putting any in, our stock will soon be exhausted. A prudent man tries to put year by year more money into his bank than he draws out. This is just what a good farmer also tries to do with his land. Every season he puts at least as much plant-food into his soil as his crops take out of it, and more if he can. In considering the sources of plant-food, we must not forget that in the atmosphere there is an inexhaustible supply of carbonic acid, and also a small amount of ammonia. But plants cannot avail themselves of these gaseous foods unless the mineral matter which they also require be present in the soil in sufficient quantity and in a proper state. When the experiment of growing plants in prepared plant-food is tried (see page 15), it is found that the omission of a single ingredient is enough to injure the growth of the plant. For these reasons it has been the practice of good farmers in all ages and in all countries to add to the soil certain substances, which experience has taught them will promote its fertility. To such substances the name of *manures* is applied.

44. Definition of a Manure.—A manure is any substance which is added to a soil in order to increase its fertility. Some manures are themselves plant-food; others act by changing some of the dormant part of the soil into an active condition; still other manures act in both ways. Another definition, then, of a manure may be, that it is any substance which is added to the soil in order to increase the amount of plant-food, either directly or indirectly.

45. Classification of Manures.—There are two or three ways in which we might group the substances applied to the land in order to increase the store of plant-food in the soil.

In the first place, we might separate such manures as have been long in use, and which require no preparation but that which can be given them by the farmer: these we may call *Natural Manures.* They include farm-yard manure, sewage, green manures, lime, marl, shell-sand, etc.

Other manures require a course of preparation before they are applied to the land; they are wholly or in part *manufactured* by the merchants who sell them to the farmer: hence they are called *Artificial Manures.* Of these we may name guano, superphosphate of lime, nitrate of soda, and sulphate of ammonia.

Another way of classifying manures is into *General* and *Special.* Any manure which, like farm-yard manure, contains every kind of plant-food, and hence can be applied advantageously for any crop to any soil, is called a *general* manure.

But there are many manures the action of which on some soils is very good, while in other cases they either produce no effect or may even be harmful. Lime is an example of this class. Useful as it is on land which is deficient in it, and also on heavy clays, it is harmful to light sandy soils. Such manures may be called *special,* since they only suit certain soils and certain crops.

46. How to select a Manure.—In considering what manure or manures it will be best to apply to the soil of a farm, we must endeavour to find out in what materials the soil is deficient, and then select a manure which will supply the deficiency. Chemical analysis will tell us the composition of the soil. And in making this analysis we must especially try to find out what substances are in the active state; for if they are only in the dormant condition, they might as well be a hundred miles off, for all the help they can give to the next crop.

Then we must study the *custom of the country.* Science has not yet arrived at such perfection as to be able to tell us, from the chemical analysis of the soil, exactly and certainly what are the substances which it requires to render it fertile. But in every part of the country farmers have been experimenting generally without knowing it, for centuries; and we ought to try to get the benefit of their experience. We must try to learn, then, what are the manures which are used on neighbouring farms, what is their effect upon the crops, and what is their cost.

47. How Manures yield a Profit.—The farmer makes his profit by putting into the soil matter—manures, seed, etc.—which cost him little, while the crops produced are worth much more money. He must therefore consider not only what manures are needed, but also which kind, if there are several that will answer the purpose, can be obtained at the lowest cost.

IX.—NATURAL ORGANIC MANURES:
FARM-YARD MANURE.

48. Nature of Farm-yard Manure—49. Composition of Farm-yard Manure—50. Quality of Farm-yard Manure—51. Treatment of Farm-yard Manure—52. How Farm-yard Manure should be applied to the Soil—53. Manure made on the Land.

48. Nature of Farm-yard Manure.—Of all the various kinds of manure now employed, that made in our farm-yards is at once the most natural, the most popular, and the one which has been longest in use. It consists of the straw of crops mixed with the dung or excrement of animals. Now both these substances have been taken from the soil, and when we return them to it, we repay to the soil some of the matter which, in the crops reaped, we have taken from it. A fair crop of wheat takes 175 lbs. of mineral or inorganic matter from every acre of ground: 25 lbs. of this are contained in the corn, and as this is sold and removed from the farm, it is lost to the land. But the straw contains the remaining 150 lbs., and by restoring this straw to the land, we shall be doing much to prevent the exhaustion of the soil.

The animals kept on the farm—the horses, cows, sheep, pigs, etc.—are fed on hay, roots, grass, corn, etc., which have been grown on the fields, and to form which much plant-food, both inorganic and organic, has been removed from the soil.

Of the food they eat, these animals use a large part to form their flesh and their bones, and to keep up their heat and their strength; but a part of the food passes through their bodies, and forms what we call their dung or excrement. Here, again, we see that when we spread the dung of animals on the land we are only returning to the soil matter which we removed from it in the form of hay, roots, etc., for the farm animals to feed on. In farm-yard manure we have *dung mixed with straw*, and we return both together to the land.

49. Composition of Farm-yard Manure.—One reason why farm-yard manure is so generally useful is that it contains a great variety of substances. No matter what substance the soil may require, this manure is sure to contain some of it. Its active portion, or that which is ready to act at once as plant-food, will be the *soluble organic matter* and the *soluble inorganic matter* which it contains, and these together usually amount to only about *one-twentieth* of the total weight, or we may say that twenty tons of ordinary farm-yard manure contain about one ton of plant-food. The following table shows the composition of an average manure, composed of horse, cow, and pig dung, with straw litter. In the first column the composition of the manure in the *long* or *fresh* state is shown; and in the second column the composition of manure which had lain in a heap for six months, and so had become well rotted.

Table showing the Composition of Farm-yard Manure.

	Long or Fresh. lbs.	Well rotted. lbs.
Water	6,617	7,542
Soluble Organic Matter	248	371
Insoluble Organic Matter	2,576	1,282
Insoluble Inorganic Matter	405	658
Soluble Inorganic Matter—		
Silica	24	25
Phosphate of Lime	30	38
Lime	6	12
Magnesia	1	5
Potash	58	44
Soda	5	2
Common Salt	3	4
Sulphuric Acid	5	6
Carbonic Acid	22	11
	10,000	10,000

There are several things to be learned from this table. We see that out of the entire 10,000 lbs. weight of fresh manure only 402 lbs. are ready to act at once as nourishment to the crops, this portion consisting of 248 lbs. of soluble organic matter and 154 lbs. of soluble inorganic matter. In the well-rotted manure 518 lbs. of such plant-food are present, and we see that by letting the manure ferment, or rot, or decompose, we increase the quantity of soluble material. Water constitutes an immense proportion of the whole manure, forming nearly three-quarters of its entire weight.

50. Quality of Farm-yard Manure.—The value of this manure depends greatly on the animals which produce it, and on the care which is taken of it.

The horse produces a hot and powerful manure, while the cow yields a cold and watery excrement. To get the best results it is necessary to *mix* well together the manure from the various animals which are kept on the farm. Birds' dung is very fertilizing, and where large numbers of fowls or pigeons are kept, their manure should be carefully preserved and added to the general heap. Old animals yield a better manure than young ones. The reason of this is, that a young animal uses up and keeps more of its food. A young beast has to form new flesh and bones, because it is growing, as well as to repair the waste of that which is already formed. An old animal, on the contrary, does not increase in size or weight, and only takes enough out of its food to take the place of that part of its body which daily wastes away. Then much depends on the nature of the *food*. Where rich, dry, concentrated food like oats or oil-cake is given, the manure will be far more valuable than if the animals have had little else but grass. It is estimated that the value of the manure produced by cattle from one ton of oil-cake is £4, 10s.; from one ton of clover-hay, £2, 5s.; and from one ton of turnips, only 4s.

51. Treatment of Farm-yard Manure.—If we go to three different farms, we shall very likely see three different ways of treating the manure produced in the farm-yard. On one farm we shall perhaps see a large manure-heap in an open yard, exposed to all the rain that falls, and standing on a slope, so that a black stream may often be seen trickling away from it. When we see this, we know at once that the farmer has never studied the *science of agriculture*, or he would not waste the best part of his manure in this way. The rain washes the soluble substances —just those which are of most value—out of the manure-heap, and they drain away and are lost.

On another farm we find a capital covered yard: the cattle and horses are in stalls, or byres, or boxes; plenty of good straw-litter is added daily; and there is a covered tank or cistern underneath some part of the yard, into which all the liquid manure drains. But there is a strong smell which reminds us of the "smelling-salts" which some ladies carry about with them, and the manure-heap is covered with a whitish dust, which the farmer calls *fire-fang*. The smell is caused by *ammonia*, and this substance must consequently be escaping into the air. It is the most valuable portion of the manure, and would cost the farmer £100 a ton if he desired to buy some. Yet he does not know that he is losing it from his manure for want of proper treatment.

The fact is that this farmer has kept his manure *too dry*. We ought to endeavour to get the manure to heat or ferment at a moderate temperature. The organic substances called humic acid, ulmic acid, etc., will then be formed by the rotting of the straw, and these acids will combine with the ammonia produced by the decay of the dung. The black liquid which is contained in properly managed manure is really a mixture of *humate of ammonia* and *ulmate of ammonia* (as the compounds of ammonia with the above-named organic acids are termed). This black liquid is *not volatile,*—that is, it will not pass into the air and escape, as ammonia by itself would do. From a properly managed manure-heap, then, there ought to be little or no smell.

When the manure is allowed to become dry and hot, *carbonic acid* is formed instead of the organic acids, and this carbonic acid combines with the ammonia to form *carbonate of ammonia.* Now this substance *is volatile,* and it flies away in the air and is lost. To prevent loss, the liquid manure should be frequently pumped up from its tank and allowed to flow over and mix with the more solid manure. If this supply runs short, water should be added to the manure-heap as required. This will keep down the temperature of the mass. All the substances should be thoroughly mixed. When the rotting or fermentation is proceeding too quickly, the manure should also be beaten down and kept close together. To make it ferment faster, it may be opened, so that air can enter more freely. The temperature of the manure-heap should be kept below 80 degrees. The degree of heat may be ascertained by means of a thermometer.

52. How Farm-yard Manure should be applied to the Soil.—The *quantity* to be applied varies with the crop: roots are generally allowed from 20 to 30 tons per acre, while for corn crops from 12 to 15 tons per acre is sufficient. On some farms the practice is to draw out the freshly made manure in autumn, spread it at once on the land, and plough it in. This can only be safely done on clay soils, rich in the substances called double silicates. Such soils can hold the fertilizing particles in their pores, and the rotting of the manure in the clay soil does great good by rendering the ground more open. On light and sandy soils the usual and proper plan is to keep the manure under cover until it is well rotted, and only to apply it to the land just before the sowing or planting of the crops which it is intended to nourish. These light soils cannot retain the manure. If it is added too soon, the rain washes it away, and it is lost to the farmer. Such soils are generally manured in the spring.

In sowing seeds, it is a good general rule not to allow the seed to be in close contact with any manure. In setting potatoes, for example, the manure in the furrows should be covered with a little soil, and the "sets" placed on the soil.

53. Manure made on the Land.—On sheep-farms the greater part of the manure is not made in yards or stables, or mixed with litter, but is dropped by the sheep on the ground where they are feeding. Other animals, too—as cows and horses—when grazing in the fields, deposit there a certain proportion of their excrement.

In all these cases the manure must be well knocked about, so that it may be spread more evenly over the soil. If this be not done, the grass will grow unequally, and will be so rank and strong in spots that it will not be liked by the stock.

Sheep should not be permitted to range as they please over the clover, turnips, or other crops on which they may be feeding. The best plan is to enclose a part of the field by hurdles, so that the animals are limited to one portion of the crop at a time. As this part is used up, the hurdles must be moved. In this way the roots, etc., are more thoroughly consumed, while the manure is evenly deposited over the entire field.

X.—NATURAL MANURES: IRRIGATION AND SEWAGE.

54. Water as a Manure—55. Good Drainage must precede Irrigation—56. Warping—57. Irrigation with Sewage—58. Sewage Farms—59. Irrigation in Hot Countries.

54. Water as a Manure.—The supply of water to crops by artificial means is called irrigation. Not only is pure water in itself a valuable plant-food, but both rain-water and spring-water contain substances dissolved in them which are capable of acting as plant-food. In many parts of the country certain fields, called water-meadows, are supplied regularly with water by means of pipes, just as we often water our gardens by means of a hose or a watering-pot. Very good crops of grass are generally obtained from these water-meadows, and they require but little manure of other kinds. As the water flows through the soil, the latter absorbs the carbonic acid, ammonia, carbonate of lime, and other nourishing materials which may be contained in the water, and stores them up in its pores ready for the use of the plants.

55. Good Drainage must precede Irrigation.—For success in irrigation it is necessary to have the land thoroughly well drained. Standing water is unhealthy and injurious to the crops. It is the flow of water through the soil that we must try to secure, and this cannot be done unless we provide numerous drains to take the water away.

Besides yielding plant-food, the water which flows through the ground brings with it *warmth*, so that the temperature of the soil is raised, and this greatly favours the growth of plants. There is also *air* dissolved in the running water, and this air acts on the dormant matter in the soil, changing some of it into the active state.

56. Warping.—In some districts, as around the Humber, the water of the rivers is extremely muddy, while the land around is very flat and low. It is then of great advantage to allow the river-water, at intervals, to flow over the land, and to cause it to stand there for a short time by means of embankments and flood-gates. While the water is standing, it deposits all its rich mud as a fine coating on the land, and is afterwards allowed to run away quite clear and bright. In this way much poor barren land has been covered with a considerable thickness (one to two feet) of rich soil. This process is called *warping* the land.

57. Irrigation with Sewage.—Although ordinary rain or river water contains a certain amount of fertilizing matter, yet we cannot deny that if it had still more it would do a greater amount of good to the land. Now, in all large towns a great difficulty has been felt of late years as to the disposal of the *sewage* or waste matter produced by all the people, and by the manufactures, etc., of the town. The usual course has been to collect this sewage by means of pipes or drains from every house; these drains join to form larger drains; and at last all the sewage is poured by a great pipe into some river, or if the town is on the coast it is allowed to flow into the sea. In this way not only are the rivers made foul and offensive, but all the sewage is lost. Now, sewage consists chiefly of human excrement, diluted and washed along by water, and it is capable, if properly treated, of furnishing a large supply of plant-food.

58. Sewage Farms.—The corporations, or governing bodies, of several of our large towns, including Birmingham, have purchased large tracts of land near the towns, and now use them as *sewage farms.* The sewage is led to the land through pipes, and the fields are so arranged that the sewage enters the soil where the ground is high and soaks down through it, running into a brook or river at a lower elevation. By running through the soil the water is *filtered,* and comes out bright and clear. The particles of the soil attract and hold nearly all the waste matter conveyed by the water. We must not think, however, that this offensive matter can enter the crops in the same state as we see it in sewage. By changes which take place in the soil all the plant-food is prepared as a perfectly bright and clear solution, in which state it enters the roots of the plant. The earthy substances called double silicates do most useful service in effecting this change; and it has even been proposed to use them medically as a dressing for wounds on the skin, because of their great powers of cleansing.

It is clear that sewage irrigation answers a double purpose: it enables the towns to dispose of their waste matter, which they could not do so cheaply and effectively in any other way; and it adds a valuable manure to the land. Like everything else, however, it requires care and judgment in its application: when an *excess* of sewage is added to the soil, its effect may be decidedly injurious.

In any system of irrigation care must be taken to give the soil a *breathing-time.* The flow of water must not be continuous, but the land must be allowed to become dry at regular and frequent intervals, so that air may enter. Sewage irrigation seems more serviceable to grass and roots than to any other crops. By its use it is not uncommon to get five or six heavy crops of Italian rye-grass in one season on sewage farms.

59. **Irrigation in Hot Countries.**—In hot countries—as India—irrigation is conducted mainly for the supply of water it gives to the crops.

In Egypt the annual overflow of the Nile is relied upon as the chief maintainer of the fertility of the soil. The rise of the Nile in June is caused by the melting of the snow on the mountains of Abyssinia, the resulting torrents bringing down immense quantities of mud. The Nile waters are allowed to spread over the fields of Lower Egypt; and as the water comes to a standstill it deposits the mud, which offers a rich store of plant-food to the crops of cotton and rice which spring up after the retreat of the waters. It will be seen that this is another instance of the process called *warping.*

XI.—NATURAL ORGANIC MANURES: GREEN MANURES.

60. What is a "Green Manure"?—61. Plants grown as Green Manures—62. Green Manures as "Keepers"—63. Other Green Manures.

60. What is a "Green Manure"?—By a green manure we understand any crop which is grown on the soil, not for the purpose of being reaped, but in order that when fully grown it may be ploughed into the soil, and may there serve as plant-food.

Some people cannot understand of what use such a practice can be. They say that, as we only return to the soil the crop which grew out of the soil, the latter is neither the better nor the worse for it. But the fact is that we do return to the soil much more than the plants composing the crop grown for green manure took out of it. We add organic matter to the soil; for the chief part of the organic matter of plants does not come from the soil but from the atmosphere, so that in the green manure the soil receives an addition of much organic matter which it did not possess before. For this reason, this plan is especially suitable to light, sandy soils, which are usually deficient in organic matter.

Another advantage is, that as the plants forming the green manure decay in the soil, they will furnish their substance as plant-food to the next crop in a very convenient way. The crops grown for green manure are hardy and quick-growing—able to send their roots deeply into the soil, and to gather together a great deal of the plant-food which the soil may contain. The crop for whose benefit we intend the green manure would not be so well able to do this; but in the green manure itself the next crop finds a good store of all that it requires.

61. Plants grown as Green Manure.—In this country white mustard, rape, rye, vetches, and buckwheat are more or less grown on purpose to be ploughed into the land to act as green manure.

Clover is grown partly for the sake of its stems and leaves, which are cut, or eaten off by sheep, and partly for the sake of its roots, which are left to decay in the soil, thereby furnishing a store of plant-food for a succeeding wheat-crop.

The tops and leaves of root-crops, potatoes, and, indeed, any part of any crop which is not more valuable for some other purpose, ought to be left on the land and ploughed in after the rest of the crop has been gathered. By doing this we shall be returning to the soil a portion of the matter removed by the crop. In this, as in many other ways, a wise farmer will endeavour to exhaust his soil as little as possible.

62. Green Manures as "Keepers."—When farm-yard manure is added to very sandy soils, it is often wasted by rain, which washes it away before the crop it was intended to nourish can use it up. On such soils it is common to sow a crop of some very rapidly-growing plant, the seed of which costs little —such as white mustard—in order that it may quickly absorb or take up all the newly-added rich farm-yard manure. The green crop of mustard, etc., is afterwards ploughed in, and the next crop, generally wheat, reaps all the benefit both of the farm-yard or other manure which was originally added, and of the organic matter obtained from the atmosphere by the preceding crop of green manure.

63. Other Green Manures.—Near the coast sea-weed or sea-ware is a favourite manure. It is applied at the rate of from sixty to eighty tons per acre, with excellent results. Sea-weed contains not only common salt, but also salts of potash and soda, besides nitrogenous matter, which latter yields ammonia by its decay. It is to these substances that sea-weed owes its value as a manure. The common fern or bracken has in some parts of the country, where it grows strongly and luxuriantly, also been cut and applied to the soil as a green manure with good results.

Peat, straw, saw-dust, bran, leaves, and soot are all vegetable substances which are useful as manures. In most cases it is better to use them (except, of course, soot) in the farm-yard first as part of the litter before putting them on the land. They usefully absorb the liquid excrement of animals, and this causes them afterwards to decay more rapidly, and so to yield plant-food more quickly, than they would otherwise do.

XII.—NATURAL INORGANIC MANURES.

64 Two Kinds of Natural Manures—65. Natural Inorganic Manures: Lime—66. How to apply Quick-lime to the Soil—67. The Use of Quick-lime as a Manure—68. Quick-lime may be injurious to certain Soils—69. Carbonate of Lime as a Manure—70 Marl as a Manure—71. Gypsum as a Manure—72. Salt as a Manure.

64. The two Kinds of Natural Manures.—The manures we have already spoken of are called *natural* manures, because they do not undergo what we usually call a process of manufacture by man. But in one sense farm-yard manure and sewage and green manures are manufactured substances, because their parts have been put together by animals or plants.

As we have already explained, plants possess the power of living upon *inorganic* or *mineral matter*, and of building up this mineral matter into their tissues or organs. Animals cannot do this, but plants can. Yet even plants find it very hard work to live entirely on inorganic matter. They grow more quickly and more strongly if we supply them with a portion of *ready-prepared* organic matter, in the shape of the manures we have already described.

As regards inorganic plant-food, we know that the plant has to obtain it entirely from the soil in which it grows. But the inorganic substances required by plants are many in number. Of some of them the soil may contain very little, and of others perhaps none. Unless the soil is naturally extremely fertile, it will clearly be very advantageous, or even quite necessary, to add to it those mineral substances in which it is most likely to be lacking, or of which it has but a small store.

65. Natural Inorganic Manures: Lime.—Lime is a well-known and popular manure. It has been in use for a very long period, but it is not so frequently and abundantly applied to the land at the present day as it was in the early part of this century. The farmers *then* were perhaps rather too fond of lime as a manure; *now*, it is possible that they hardly use it enough.

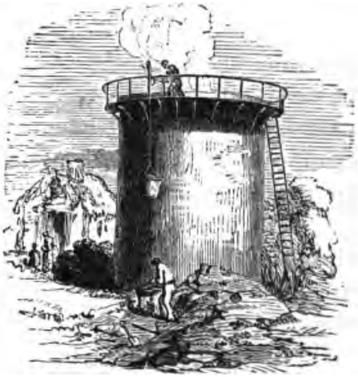


FIG. 22.—Lime-Kiln.

When we speak of lime we mean *quick-lime*. This substance is obtained by burning chalk, or any pure limestone, in a kiln. The heat drives carbonic acid gas out of the limestone, and oxide of lime remains. To this oxide of lime the name of *quick-lime* is universally applied, because of its *quick* or burning properties. It is used by masons to make mortar. They pour water on it, and so convert it into *slaked lime*. When this slaked lime is exposed to the air it joins with carbonic acid gas (from the air), and becomes *carbonate of lime* once more.

66. How to apply Quick-lime to the Soil.—If the lime is carted out to the fields, placed in small heaps, and left exposed to the weather, it will very soon cease to be quick-lime. It will combine with moisture and with carbonic acid gas, and will become carbonate of lime once more. All the trouble and expense of burning the limestone will in this case have been thrown away. The proper plan is to *slake the lime* immediately it is thrown out of the cart, and then to *cover it over* with a few shovelfuls of earth until it can be spread over the soil. Only enough water should be added to cause the lime to crumble to a fine powder: an excess of water should be avoided. After spreading, the lime should be *immediately* harrowed in. Ploughing would bury the lime too deeply; for, strange to say, lime has a great tendency to work down lower and lower into the soil. In the old days, when lime was freely used, and when it was ploughed in, a hard layer or *lime-pan* was often formed in this way.

67. The Use of Quick-lime as a Manure.—(1.) Lime acts as a "sweetener" of sour soils. The sourness of most soils is due to the presence of an *excess* of vegetable matter, whereby large quantities of the organic acids are produced. Now, the quick-lime combines with these acid substances, and so sweetens the soil. The effect is soon seen in the changed appearance of the herbage. The wiry tough grasses, sedges, and rushes disappear, and their place is taken by more tender and juicy species of grass, which are much preferred by sheep and cattle. Quick-lime also acts very usefully on soils which are made barren by the presence of a quantity of green vitriol or sulphate of iron. The lime takes the place of the iron, and so sulphate of lime (or gypsum) is formed. Now this gypsum is a useful plant-food.

(2.) Lime acts chemically on clay soils, helping to form the *double silicates*, the presence of which is so valuable. Pure clay is silicate of alumina; but when this comes into contact with quick-lime, a *silicate of alumina and lime* is formed. The latter is a very valuable substance to have in a soil; while so far as furnishing plant-food is concerned, the single silicate (silicate of alumina) is of no use at all. If the double silicate comes into contact with any ammonia, the lime is *turned out*, and the ammonia takes its place. Then we have the silicate of alumina and ammonia, which is the most valuable of the four double silicates which occur in our soils.

(3.) Lime sets free some of the potash in the soil. Most soils contain a little silicate of potash; but the lime combines with the silica and *turns out* some of the potash. Lime acts in the same way with silicate of soda. The potash and soda which are thus set free are ready to act as valuable plant-foods. In this way lime changes some of the *dormant* matter into *active* matter, and so improves the fertility of the soil.

68. Quick-lime may be injurious to certain Soils.—Lime is most useful on clayey soils and peaty soils; but it is often found to act injuriously on sandy soils. The fact is, that light porous soils, such as these sandy soils are, cannot spare any of their organic matter. Now quick-lime soon uses up the organic matter in such soils, so that its action on them may be injurious. By the use of lime we may often obtain much heavier crops; but it must not be forgotten that we thereby rapidly exhaust the land, and that we ought, consequently, when we use much lime, to add an abundance of other kinds of manure.

69. Carbonate of Lime as a Manure.—Limestone is often applied advantageously to soils which would be injured by the use of quick-lime. The white, pure, earthy limestone called *chalk* is preferred, where it can be readily obtained, as in the south and east of England. Chalk is nearly pure carbonate of lime. It should be dug or quarried, broken into lumps, and applied to the land in *winter*. The chalk is then moist or full of water, and the winter frosts cause the water to burst the lumps of chalk and reduce them to the state of a fine white powder. When rain falls it dissolves some of the carbonate of lime, and the solution forms a very valuable plant-food, for lime is required, more or less, by all plants.

70. Marl as a Manure.—The term "marl" is properly applied to a limy clay. The presence of carbonate of lime in marl, or indeed in any soil, is ascertained by pouring a little weak hydrochloric acid upon a sample. The acid drives carbonic acid gas out of the carbonate of lime, and we see it bubble up or effervesce. In former times—say up to thirty or forty years ago—beds of marl were largely dug, and the marl spread over the surface of the fields. Large pits, called "marly-holes," are still to be seen in many parts of England, especially in Cheshire, and the possession of one of these marl-pits was considered as a valuable addition to a farm. Marls vary very much in composition, and this is one reason why their use has gone out. Green marls often contain considerable quantities of soluble silica, of phosphoric acid, oxide of iron, etc., while other marls may contain little or none of these substances. Of course marls improve the quality of light soils, but the expense of carting a quantity of marl large enough to effect any great improvement is very heavy.

Any farmer who intends to apply a quantity of marl to his soil should first have the marl analyzed by a competent chemist. He will then learn whether it contains substances which will repay the trouble and expense of digging and carting it.

71. Gypsum as a Manure.—The chemical name for gypsum is *sulphate of lime.* When burnt it forms the white powder called *plaster of Paris.* To the farmer it is as useful unburnt as burnt. Its use is beneficial to grass, and to peas, beans, and clover. Gypsum supplies sulphuric acid and lime to the growing plant. Its value will evidently depend on the amount of these substances already in the soil.

72. Salt as a Manure.—Common salt is a compound of a metal called *sodium* with a gas named *chlorine.* Land within a few miles of the sea seldom needs any salt, for the spray from the waves is carried inland by the wind. An excess of salt is highly injurious to growing crops. Applied in small quantities to rich land, salt is useful in checking an undue growth of straw or herbage. On good cornland in wet seasons there is a great length of straw produced, while the ears are small and the yield of corn is light. The application of a dressing of salt to such land is found to stop the growth of the straw, and to allow the plant to give all its power to the production of well-filled heavy ears.

Mangel-wurzel is a crop which requires a good supply of salt; and it is also liked by cabbages, beans, and onions. Analysis of the ash of all these plants shows the presence of a large amount of common salt.

XIII.—ARTIFICIAL MANURES.

73. What is an Artificial Manure?—74. Use of Artificial Manures—75. Introduction of Artificial Manures—76. Bone as a Manure—77. Composition of Bone—78. Fermented Bones—79. Action of Carbonic Acid on Phosphate of Lime.

73. What is an Artificial Manure?—Usually the word *artificial* means *made by man*. In agriculture we apply this term not only to manures, such as super-phosphate of lime, which are manufactured, but also to others, such as guano, which are brought from foreign countries, and which are, in that sense, not *natural* to the land in which they are used.

74. Use of Artificial Manures.—Artificial manures are generally *special* manures. They do not restore to the land *all* the substances of which it has been robbed by the crops which have grown on it, or by the animals which have fed on these crops, but they usually return some *one or two* substances of which the soil has lost a great deal, and of which it stands in need. In this they differ greatly from farm-yard manure, which is called a *general* manure, because it contains *all* the plant-food needed to make the soil fertile.

One good property of artificial manures is that they are generally *concentrated* or very strong. In farm-yard manure, sewage, etc., we have to move about a great deal of water, which is labour thrown away, as it were. For instance, when we have carted one hundred tons of dung to a field, we know that about seventy tons of this is nothing but water. Now in artificial manures, as superphosphate of lime, guano, nitrate of soda, etc., there is very little water, and there is therefore less waste of labour in moving it about. If we have to take our manure a long way, or to fields on steep hill-sides where the labour of hauling is very great, it may be better to use several kinds of special or artificial manures, because of their less weight, than to incur the expense of carting a great weight of farm-yard manure.

75. Introduction of Artificial Manures.—The use of artificial manures is entirely of modern date, and is due to the application of scientific principles to agriculture. The farmers of the eighteenth and preceding centuries were content to treat their land as their fathers had done before them; but in this the nineteenth century the farmers have found that it is absolutely necessary, if a man is to farm successfully, to introduce new methods, new machinery, and new manures.

76. Bone as a Manure.—It may have been an accident that led some farmers to observe that where bones decayed on the land, especially on grass land, a vigorous plant-growth took place. In the early part of the present century it became generally known that the application of bones to old pasture-land would produce a wonderful improvement in the grass. The change effected by this means, especially in some of the dairy farms of Cheshire, where the land had been laid down in grass for a great number of years, was indeed remarkable.

But whole bones take a long time to decay in the soil, and it was soon found to be advantageous to break them up. Machines were made to do this, and the bones were smashed into pieces small enough to drop through the meshes (placed half an inch apart) of a sieve, and hence were known as *half-inch bones.* Last of all, the bones were broken up very fine, and were sold as *bone-dust,* which is consequently a manufactured or artificial manure.

77. Composition of Bone.—If a bone be burnt on a clear fire, or boiled for a considerable time, it will be found to lose about one-third of its weight. The heat drives away the soft or animal part of the bone—a substance called *gelatine,* from which *glue* is made. On the other hand, by soaking a bone in weak hydrochloric acid, we can remove the hard or mineral portion. This is mainly a substance called *phosphate of lime,* consisting of phosphoric acid combined with three parts of lime. When ordinary bones are applied to any soil, the gelatine yields, by its decomposition, some *ammonia,* for it is a nitrogenous substance. The insoluble phosphate of lime is slowly changed by the action of rain-water into *reduced* phosphate of lime, in which phosphoric acid is combined with only *two parts* of lime. This reduced phosphate is slowly soluble in rain-water; and as it is dissolved, it is absorbed by the roots of plants, and so furnishes them with a kind of plant-food of which they all stand more or less in need. It is clear that bones must be considered as a very valuable manure.

78. Fermented Bones.—Another very useful way of preparing bones to act as manure is by fermenting them. The bones are piled in large heaps, well watered, and covered with saw-dust, ashes, or earth. The heap soon becomes very hot, and the bones grow soft. The animal matter in the bones is quickly decomposed, and the mineral matter is altered by the loss of some of its lime.

79. Action of Carbonic Acid on Phosphate of Lime.—Carbonic acid, contained in water and in air, takes one part of lime away from the phosphate of lime. We have already explained that ordinary phosphate of lime consists of one part of phosphoric acid combined with three parts of lime, thus—

$$\text{Phosphoric Acid}\ldots\ldots\ldots\ldots\ldots\left\{\begin{array}{l}\text{Lime,}\\ \text{Lime,}\\ \text{Lime,}\end{array}\right.$$

and for this reason it is often called the *three-lime phosphate*, or the tri-calcic phosphate, which means the same thing.

When the carbonic acid takes away one part of lime, then we have a *two-lime phosphate* (or bi-calcic phosphate) left, thus—

$$\text{Phosphoric Acid}\ldots\ldots\ldots\ldots\ldots\left\{\begin{array}{l}\text{Lime,}\\ \text{Lime,}\end{array}\right.$$

and the third part of lime goes to join with the carbonic acid to form *carbonate of lime:*

$$\text{Carbonic Acid}\ldots\ldots\ldots\ldots\ldots\ldots\text{Lime.}$$

XIV.—SUPER-PHOSPHATE OF LIME AS A MANURE.

80. Slow Action of Bone Manure—81. Baron Liebig's Discovery—82. What is Super-phosphate of Lime?—83. Use of Super-phosphate—84. Objections to Super-phosphate—85. The "reduced" Super-phosphate preferable—86. Mineral Super-phosphates—87. Price of Super-phosphate.

80. Slow Action of Bone Manure.— Although by previously grinding bones to dust, or by fermenting them, they are afterwards more easily changed in the soil into the *reduced* or *bi-calcic* phosphate of lime, yet even this substance dissolves *very slowly* in rain-water. Land treated with ground bones shows a *little* benefit the first season; then rather more for the next year or two; and it will be some ten or twelve years in all before the bone manure is used up. This was considered very slow work, and people began to inquire how the mineral matter of the bone could be rendered more soluble.

81. Baron Liebig's Discovery.—It was just at this time, in 1840, that Baron Liebig, a great German chemist, made known his discovery, that if bones were mixed with sulphuric acid a *super-phosphate of lime* was formed, which was easily and quickly soluble in water. Merchants immediately began to manufacture this super-phosphate of lime; farmers were glad to buy and use it; and immense quantities of it are now applied to the land by British farmers every year.

82. What is Super-phosphate of Lime?—Sulphuric acid is a very strong acid. It is able to take away *two parts* of lime from the phosphate of lime, so that we have left a substance in which all the phosphoric acid is *concentrated* on *one part* of lime:—

Phosphoric Acid....................Lime.

Hence the name super-phosphate, which means that there is an excess of phosphoric acid. This substance is also called mono-calcic phosphate of lime, or *one-lime phosphate.* But what does the sulphuric acid do with the two parts of lime which it seizes? It combines with the lime to form sulphate of lime, or gypsum.

83. Use of Super-phosphate.—Great good has certainly resulted from the application to many, or indeed most soils, of the super-phosphate of lime. On old pasture-land its effect is often wonderful; this is due to the fact that it returns to the soil the phosphoric acid and lime which have been taken from it year after year. Cows crop the herbage, and in their bodies the grass is digested, and most of it goes to form milk, bone, and flesh. Now we know that bone contains much phosphate of lime; and every thirty gallons of milk contains one pound of the same substance. If the grass be eaten year after year, and no phosphate of lime be returned to the soil, it is clear that the land will become exhausted of this substance. But we have learned that the fertility of any soil depends on that necessary portion of plant-food which is present in *least* abundance. The soil may contain plenty of other useful matter, but if it is lacking in phosphate of lime, it cannot grow good grass crops. This was the condition, many years ago, of much of the pasture-land of Great Britain, and the improvement effected by the supply of super-phosphate of lime was very great; it had been *the one thing wanting*. All green crops are much benefited by this manure. To turnips it seems especially useful, causing the young plants to grow so quickly that they soon get above the reach of the fly. It should be applied at the rate of from 3 to 6 cwt. to an acre. It is estimated that 300,000 tons of super-phosphate of lime are now used annually as manure in the British Isles.

84. Objections to Super-phosphate.—It is said to be possible to have too much of a good thing; and so it is possible to have the phosphate of lime in *too soluble* a condition. On light sandy soils there is great danger of the super-phosphate being washed out of the soil by heavy rains before the crops can make use of it. This manure, therefore, should not be applied till the spring of the year. Again, being so soluble, all the super-phosphate is dissolved by water soon after it has been applied to the soil, and the young plants feed so greedily on it that they make very rapid progress. But in so doing they *use up* all the super-phosphate, and have none left on which to make steady growth. This is not unlike the case of a boy who has a large cake given to him to last him for a week: if he eats it all up the first day, he must "go short" for the rest of the time.

85. The "reduced" Super-phosphate preferable.—By using *less* sulphuric acid on the bones, or by *adding* bone-dust to the super-phosphate of lime, we can obtain the bi-calcic phosphate of lime; and this is to be preferred, as a manure, to the more soluble mono-calcic phosphate. The bi-calcic, or two-lime phosphate, is generally called "reduced super-phosphate." Since it is not so soluble, it is not so easily washed out of the soil, and its effect as a manure, though not so rapid, is more lasting. Dissolving but slowly in the moisture contained in the soil, it yields a steady supply of phosphoric acid and lime to the plant throughout the whole of its growth.

86. Mineral Super-phosphates.—Not long after Liebig's discovery was made public, an Englishman, Sir J. B. Lawes, who has devoted his whole life to the science of agriculture, suggested that since certain beds of rock were composed of phosphate of lime, these might be used instead of bones in the manufacture of the super-phosphate. His suggestion was at once adopted; and it was a very good one, for it has enabled this valuable manure to be sold much more cheaply than could otherwise have been the case. In England, beds of *coprolites,* round grayish or black

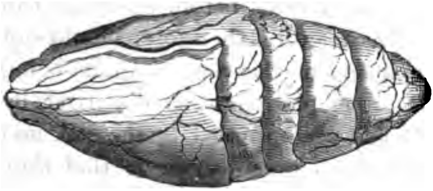


Fig. 23.—Coprolite.

lumps, about the size of an egg, occur in Suffolk, Cambridgeshire, etc. They were called coprolites because they were formerly thought to be the fossil dung of certain animals; but this is not generally the case. They are composed of impure phosphate of lime. At Bala, in North Wales, there is a bed of rock several feet in thickness formed of the same mineral. In foreign countries there are great deposits of coprolites worked in Carolina, and beds of phosphate in Spain, Portugal, Canada, and Norway. When this mineral phosphate is ground up, and mixed with about half its weight of sulphuric acid, a super-phosphate of lime is formed, which is nearly equal as a manure to that obtained in the same way from bones.

87. Price of Super-phosphate.—The way of selling this manure is somewhat singular. It is sold according to the amount of "soluble phosphate" which it contains. When warm water is added to super-phosphate of lime, it dissolves out all the mono-calcic sulphate. This water is poured away, the water dried up by gentle heat, and the residue or substance which remains shows the weight of "soluble phosphate" present in the sample. The present practice is to sell the super-phosphate by the ton, at so much *per unit*—that is, so much for each part of "soluble phosphate." If the sample contains twenty per cent. of this, and the price is four shillings per unit, then the manure costs £4 per ton (20 × 4 = 80 shillings, or £4); if it contains twenty-five per cent. of mono-calcic phosphate, and the price agreed on be five shillings per unit, then the price is 25 × 5 = 125 shillings, or £6, 5s. per ton.

Many farmers now buy the super-phosphate, and then reduce it for themselves by adding one ton of bone-dust to every two tons of super-phosphate. They know that in this manner they get the two-lime phosphate, which is a more certain and lasting manure.

The manufacturers of super-phosphate find that when this manure is kept for a few months in stock, it goes back, or becomes in part changed to the state of the reduced or two-lime phosphate. This change is a loss to the manufacturers, but it is really a gain to the farmers.

XV.—NITROGENOUS MANURES.

88. Why Plants require Nitrogen—89. Guano—90. Value of Guano as a Manure —91. Sulphate of Ammonia as a Manure—92. Nitrate of Soda as a Manure —93. Nitrate of Potash as a Manure.

88. Why Plants require Nitrogen.—We have seen that within the leaves of plants great changes are effected in the plant-food which is absorbed by the root-hairs, or which enters through the pores on the under surfaces of the leaves. The carbonic acid, ammonia, water, mineral matter, etc., taken in are decomposed, and their elements are formed into fresh compounds, which are then distributed through the plant, and help it to grow. Now the compounds called starch, gum, sugar, cellulose, and oil, are made of the three elements carbon, hydrogen, and oxygen. But the important compounds known as albumen, gluten, and legumin require in addition the element *nitrogen.*

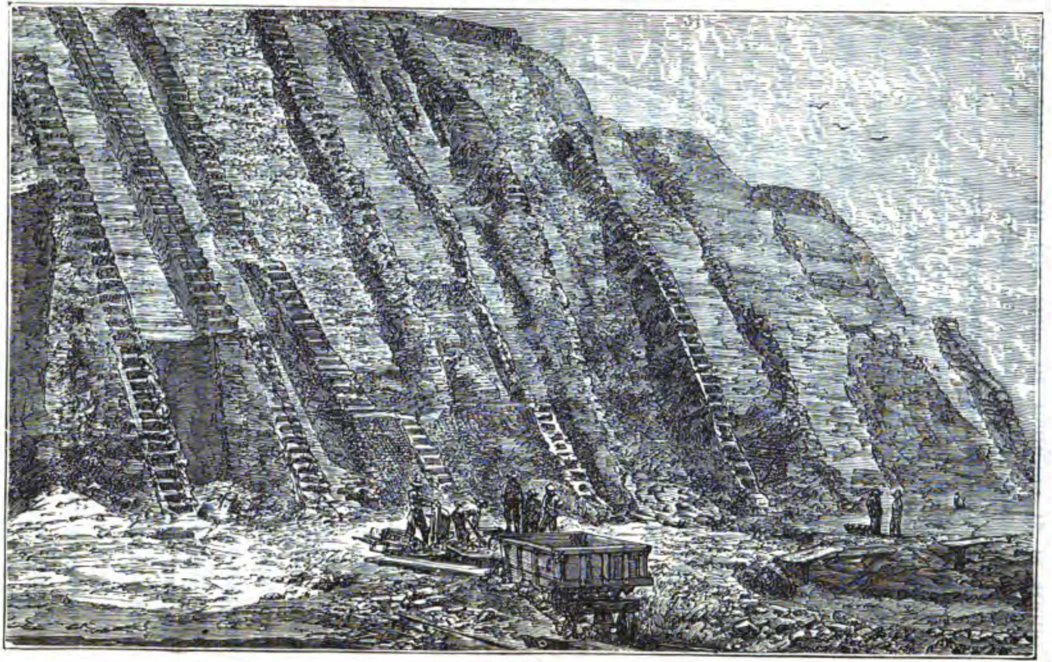
We know that in the air there is an immense store of nitrogen in its pure gaseous form. Yet although plants are thus surrounded by nitrogen, it is found that they cannot feed on this element when it is uncombined with any other. When the nitrogen combines with hydrogen to form ammonia

(NH_3), the plants eagerly absorb this substance, and use it to make the nitrogenous compounds which are absolutely necessary to their proper growth. Besides ammonia there are several other compounds containing nitrogen, such as the *nitrates*, on which our crops can feed.

89. **Guano.**—In the year 1839 a cargo of a substance called guano was brought to Liverpool. When it was applied to the land it was found to produce wonderful results as a manure; and its use has continually increased since the time of its first introduction.

Guano is mainly composed of birds' dung, and is brought from certain islands (the Chinchas, etc.), off the coast of Peru, in South America. Countless numbers of sea-birds have lived on these islands for thousands of years, and as rain very seldom falls, their excrement has accumulated to a depth of as much as two hundred feet. It is now dug and shipped to this country, where it is sold at a price of about £14 per ton.

Good fresh guano has a pungent smell, due to the ammonia it contains. By adding to the guano some saw-dust wetted with sulphuric acid, the ammonia is *fixed*, so that its loss is prevented. But guano also contains much phosphate of lime, and we know that the sulphuric acid also acts on this substance, rendering it more soluble. Guano which has been treated in this way with sulphuric acid is called *dissolved guano.* One hundred tons of Peruvian guano will yield from ten to twelve tons of ammonia, and from twenty to thirty tons of calcic phosphate. The



BED OF GUANO IN THE CHINCHA ISLANDS.

true Peruvian guano can be distinguished by its light weight: a bushel of it should not weigh more than seventy pounds.

90. Value of Guano as a Manure.—Next to farm-yard manure, guano is perhaps the most valuable manure we possess. It is most effective on strong clay soils, but it will do good anywhere. It is an excellent manure for wheat, for potatoes, green crops, and pasture-land. For wheat, about 2 cwt. per acre should be harrowed in just before the seed is sown. When rain falls, it dissolves the ammonia and the soluble phosphate of lime out of the guano. This is absorbed as plant-food by the root-hairs. The solution rises through the stem into the leaves, and is there manufactured by the help of sunlight into the nitrogenous substances—albumen, gluten, legumin, etc.—of which we have spoken.

91. Sulphate of Ammonia as a Manure.—In making gas from coal, a substance called *gas-liquor*, or *ammonia-liquor*, is obtained, which contains a certain amount of ammonia (about one half-hundredweight of NH_3 to one ton of gas-liquor). This gas-liquor may be diluted with about four times its weight of water and applied to the land by means of a water-cart; or it may be strongly heated, and the ammonia, which the heat will drive off, led into vessels filled with sulphuric acid. When the latter plan is adopted, sulphate of ammonia is formed by the combination of the sulphuric acid with the ammonia. This substance acts very rapidly when dissolved in water and applied to corn, grass, or root crops. In the case of mangels it is found, however, that the sulphate of ammonia causes such an absorption of water by the plants that although a very heavy crop is produced, yet the mangels are too watery to be really good food.

Soot contains a little sulphate of ammonia, to which its value as a manure is largely due.

92. Nitrate of Soda as a Manure.—Nitrate of soda is a white crystalline substance produced by the combination of nitric acid with soda. It forms thick beds in the soil of Peru, Chili, and Brazil, from which countries it is exported to Europe. One hundred pounds of nitrate of soda contain about sixteen pounds of nitrogen. Not only does nitrate of soda supply nitrogen to the growing crops, but it also acts powerfully on any substances in the soil which only require to become soluble in order to act as plant-food. For this reason, nitrate of soda has been said to act *like a whip;* and if there is not plenty of good stuff in the land for it to work on, it will not act beneficially. On good, well-farmed land nitrate of soda, applied in the spring, causes a remarkably sudden growth. On poor land its action may be good for a season or two, but it will greatly impoverish such soil. When a tenant wishes to get all he can out of the soil before leaving his farm, he applies frequent dressings of this manure.

93. Nitrate of Potash as a Manure.—Nitrate of potash costs too much to be used alone as a manure; but wood ashes contain this substance, and for this reason a sprinkling of them has a good effect. *Kainite* is the name given to certain potash salts (chiefly sulphate of potash) of which large beds occur at Stassfurt in Germany. It is an excellent plan to mix kainite with farm-yard manure, for it absorbs and fixes the ammonia of the manure, and in doing this the kainite itself becomes changed into nitrate of potash.

Woollen rags, shoddy, flesh, blood, hair, horns, hoofs, and *feathers* are all useful manures, because of the nitrogen which they contain. All these substances are more or less used by the manufacturers of artificial manures.

XVI.—PRINCIPLES REGULATING THE USE OF MANURES.

94. How Manures came into Use—95. Science explains the Action of Manures—96. Changes in the Soil caused by the Growth of Crops—97. Continuous growth of Corn—98. Manures sometimes have no Effect—99. Manures supplement the Supply of Plant-Food in the Soil—100. An Excess of Manure is useless.

94. How Manures came into Use.—The savage tribes that inhabited this and other countries in early times had no knowledge of manures and no need for them. Men in those days lived by hunting wild animals, and by eating such fruits as grew wild. After a time the cultivation of the soil was commenced, and no doubt our ancestors—thousands of years ago—found out that the *same soil* would not grow good crops year after year. But this did not lead them to apply manure to the soil. In those days the land belonged to the entire tribe, and not to any particular person or persons, so that when the soil in one place was exhausted, it was only necessary to move on a little and cultivate a fresh patch of ground. The population was very small and their needs were few.

Then, as time passed on and the number of people living in any country increased, the land became the property of certain individuals, and, instead of moving about, people dwelt on their own land, and were obliged to make the best of it year after year. It would soon be discovered that where animals dropped their dung, there the crops were better, and so the custom of preserving and applying farm-yard manure would be commenced.

Then it would be noticed that after land had been left uncultivated, because of its barrenness, for a number of years, its fertility seemed to return to it. In this way the custom of letting the land *lie fallow* for a year or two, after taking two or three crops from it, would be introduced.

95. Science explains the Action of Manures.— All these things were done, in the first place, because it was found by experience that the result was good. Farmers did not know *why* they did these things; they knew that their fathers had done so, and they knew that their crops would be better if they did so.

As wars became less frequent, and as civilization advanced, the study of the different sciences was taken up, and inquiries began to be made into the *reasons* of things. Agriculture, however, seems to have been one of the last sciences to make progress. We can hardly say that the true science of agriculture is fifty years old yet. Farmers have been slow to learn; but bad seasons and foreign competition have at last forced them to move, and a most wonderful advance has been made within the last ten years. Among the most important results of this advance has been the understanding of the real nature and use of manures.

96. Changes in the Soil caused by the Growth of Crops.—If the crops we grow were suffered to decay on the ground, the soil would grow richer year after year. More than nine-tenths of the weight of any plant is obtained by it from the atmosphere—the mineral matter, or ash, which alone is entirely supplied by the soil, being very little by weight, although it is quite indispensable. By allowing crops to rot on the ground, we should consequently add to the soil matter which the plants had taken from the air. In this way a great thickness of rich vegetable mould has been formed by the growth and decay of forests in tropical regions.

To farm scientifically, we must know the composition of the soil, and also the composition of the crops we grow on it. Chemistry will tell us this. And then, by means of manures, we must return to the soil as much of each substance as we remove in the crops. If we want the land to become more fertile, we must add more matter than we have taken away.

97. Continuous Growth of Corn.—After what we have said about the exhaustion of the soil and the consequent necessity for a rotation of crops, it may seem impossible to obtain good crops of wheat off the same land for many years in succession. Yet this has been done with perfect success; and it might be done, under the same conditions, by every farmer who knows how to combine practice with science. On the two or three farms where alone this system of a continuous growth of corn has as yet been attempted, it is found that three things are necessary to success:—

(1.) A soil of loamy clay, rich in silicate of alumina and in the double silicates.

(2.) Thorough cultivation, the steam-plough being much used.

(3.) A liberal use of manures.

The soil is so broken up, turned over, and deeply stirred that every year a large quantity of dormant plant-food is rendered active. Owing to the presence of much clay there is a great *reserve* of silica in the soil, and every year a fresh portion of it becomes soluble. Then by the addition of guano and other artificial manures, all the substances removed by the corn are restored to the soil, and so its fertility is maintained. It is true that the cost of these manures is heavy (being as much as fifty shillings per acre yearly), but the value of the crop not only pays for this and all the other expenses, but leaves a fair profit for the farmer.

98. Manures sometimes have no Effect.—It is not unfrequently the case that no apparent benefit results from the application of a certain manure. This may be due to several causes:—

(1.) The land may be already so fertile as to be producing crops as heavy as can be obtained. A rich virgin soil will grow excellent crops for several years without requiring any manure.

(2.) The land may be water-logged. When a field is badly drained, or not drained at all, so that the pores of the soil are kept full of standing water, it is found that little good results from the application of manure. The fact is, the roots cannot then make use of it.

(3.) The land may be exhausted, and the manure only a "whip." A good dressing of farm-yard manure would work a wonderful change in an exhausted soil, while a liberal application of nitrate of soda (without any other manure) to the same soil would be of no effect. Nitrate of soda acts splendidly on good rich soils, "whipping" into activity the store of dormant plant-food which exists in such soils; but its action on poor lands is *nil*, for these have lost their plant-food (if they ever had any), and cannot respond to the "whip."

(4.) The manure may not be of the right kind. A soil may be deficient, say, in *potash*, and consequently will be unable to grow good turnip crops. To improve matters, the farmer adds a large quantity of *super-phosphate*, and is surprised to find that no good results from this. But the fact was that the soil wanted potash, and the farmer gave it phosphoric acid and lime, substances of which it already had enough. When a carpenter is making a box, and runs short of *nails*, it is of no use to give him more *wood;* and so, in selecting a manure, our money will be thrown away unless we choose one which will give to the soil some kind of plant-food in which it is *deficient.*

99. Manures supplement the Supply of Plant-Food in the Soil.—When the true nature and use of manures are understood, we are more likely to apply them with profit and success. The original stock of plant-food, either in an active or in a dormant state, contained in the soil, ought to be the farmer's main reliance. Manures are introduced either to aid in the change from the insoluble to the soluble condition, or to supply some necessary article of plant-food in which the soil is deficient. Manures are, indeed, *supplemental* sources of plant-food, the soil itself, in all good systems of farming, being the *main* source of nutriment to the growing crops.

100. An Excess of Manure is useless.—It is a great mistake to suppose that if we go on increasing the amount of manure added to the soil we shall get a corresponding increase in the value of the crop. There is a limit beyond which it is useless to add more manure. Thus, in one experiment which was tried, it was found (1) that with no manure at all the land produced a crop of thirteen tons of mangels per acre; (2) after applying thirteen loads of farmyard manure to the acre, the crop was twenty-seven tons per acre; (3) when the quantity of manure was *doubled*, twenty-six loads to the acre being applied, the crop was twenty-eight tons per acre, showing an increase of only one ton of mangels for the second thirteen loads of manure.

APPENDIX.

QUESTIONS AND EXERCISES ON AGRICULTURE, SECOND YEAR'S COURSE.

I.

1. What are your reasons for thinking that plants require food?
2. From what source does a plant obtain its first supply of food?
3. Explain how it is that seeds do not sprout in a dry soil.

II.

4. Whence does a plant obtain food after it has used up the store in the seed?

5. Name any inorganic substances found in the ash of plants. Where did the plant get them?

6. How could you prove that all plants contain carbon? Suppose that a log of wood weighs one hundred pounds, how much of this weight is carbon?

7. If this log of wood be burned, about what weight of ashes will remain? What do you call the part of the wood which the heat drives away?

III.

8. Of what use is a knowledge of botany to a farmer?

9. Name the organs of an ordinary flowering plant, and state the use of each organ.

10. Name three plants which are *annuals*, three *biennials*, and three *perennials*. Why does a farmer let biennials grow for only one year?

IV.

11. Have plants any mouths? Where would you look for them, and what are they called?

12. On what part of the air do plants largely feed? How does this substance get into the air?

13. On what part of the soil do plants feed? How does water help plants to feed on the soil?

14. What is ammonia? Where does a plant obtain it?

15. Name any substances which are manufactured by plants. What is necessary to enable these changes to go on?

V.

16. Why is wheat called a *silica plant?*

17. How much mineral matter does an average crop of wheat remove from one acre of land?

18. Name all the mineral substances which must be present in the soil if it is to grow a good crop of wheat.

VI.

19. Why is wheat said to exhaust the soil of a farm more than turnips or clover, although the latter crops draw a much greater weight of mineral matter from the soil?

20. When is the soil said to be "clover-sick"? What causes this sickness, and how would you remedy it?

21. Why is the turnip called a *potash plant?*

VII.

22. Classify our ordinary farm-crops according to the inorganic compounds which they specially draw from the soil.

23. What is meant by the *rotation of crops?* What are the advantages of changing the crop grown on each field yearly?

24. Describe the Norfolk system of rotation.

25. Draw up a system of rotation of crops suitable for a rich clayey soil.

VIII.

26. How is it possible to maintain the fertility of the soil, and yet to draw heavy crops from it yearly?

27. State all the ways in which we can increase the amount of active plant-food in the soil.

28. What is a manure? How may we classify manures?

29. What principles should guide you in applying manure to the soil of a farm?

IX.

30. Is farm-yard manure composed of few or of many substances? Name any substances in it which are ready to act as plant-food.

31. On what does the value of farm-yard manure depend?

32. What means would you adopt to keep the manure from loss after it had been made?

33. Point out the danger of allowing farm yard manure to become dry. How would you test the temperature of a manure heap?

X.

34. What is meant by *irrigation?* Of what advantage is it to a crop?

35. How does *warping* improve the character of the soil? In what part of England is it largely practised?

36. How would you apply *sewage* to the soil of a farm? For what crops is it most beneficial?

XI.

37. How does a green manure benefit the soil?

38. What plants are grown in order that they may be ploughed into the soil?

39. For what purpose are green manures often used on sandy soils?

XII.

40. How can quick-lime be obtained from chalk?

41. How would you apply quick-lime to the land, so as to get the greatest amount of good work from it?

42. Point out the action of quick-lime as a manure.

43. To what soils is quick-lime most beneficial, and to what soils does it sometimes do harm?

XIII.

44. Explain what is meant by an *artificial* manure.

45. Of what materials is a bone composed?

46. How do bones act as a manure when applied to the soil?

47. How would you prepare bones to act more rapidly as a manure?

XIV.

48. Three kinds of phosphate of lime are known: give the chemical composition of each.

49. Explain the meaning of the word *super-phosphate.*

50. Why do many farmers prefer the *two-lime* phosphate to the *one-lime* phosphate? What other names do you know for these substances?

51. How did Liebig change the three-lime phosphate into the one-lime phosphate very rapidly?

XV.

52. Name any manures which can supply *nitrogen* to a growing plant.

53. What is guano? From what countries is it obtained, and at what price is it sold?

54. On what kind of land will nitrate of soda be most useful? At what time of the year would you apply it, and why?

XVI.

55. Explain as well as you can what led to the use of manures.

56. A Cheshire farmer has obtained good crops of corn for more than twenty years in succession from the same land. How do you account for his success?

57. Under what circumstances are manures of no use?

THE END.

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